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Methods for Vegetation Sampling and Analysis on Revegetated Mined Lands

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PREFACE

Revegetation is perhaps the most efficient and practical
means of returning lands disturbed by surface mining to a
productive capability. The challenge now, in the face of
expanding energy concerns, is to assure that revegetation
techniques adequately provide the site protection stand-
ards and other requirements imposed by society. Unfortu-
nately, methods for assessing the success of revegetation
are not well defined, nor are uniform standards available
by which that success can be achieved. Normally, the
relative success of revegetation is judged on the basis of
a comparison of various attributes of vegetation with a
reference area. However, complete standardization of
methods of sampling vegetation is not available, and
probably is not desirable, because no single method can
satisfy all objectives.

This handbook is intended to provide an introduction to
some of the major vegetation sampling methods that have
been found useful for evaluating revegetation success.
The characteristics of cover, production, density, and
species diversity are the most useful for this purpose, and
are discussed in some detail as they relate to revegetation
of improved pastures, grazing lands, and woodlands. In
addition, the problems and limitations of vegetation
sampling are treated in terms of general vegetation types
the sampler or inspector is likely to encounter. No pretext
is made of providing an exhaustive treatment of the sub-
ject of vegetation sampling. However, selected references
are included and should prove to be helpful in various
circumstances. This handbook should be useful for both
the seasoned professional and the novice field worker. It
was originally prepared for the specific use of Region IV
of the Office of Surface Mining, but has since been
expanded and should be of use to all personnel interested
in evaluating revegetation success on mined lands.

RESEARCH SUMMARY

This handbook outlines methods of sampling vegeta-
tion for the comparison of revegetated mined lands and
reference areas as specified by Federal regulations im-
plementing the Surface Mining Control and Reclamation
Act of 1977. The various components of vegetation sam-
pling are discussed in detail; however, only those
methods proven to have a high degree of accuracy and
precision are included. Selection of reference areas and
sampling schemes are covered in addition to production,
cover, and density sampling methodology. A viable
method of comparing species diversity of revegetated
and reference areas is presented. A statistical section
outlines sample size determination and comparison of
reference and revegetated areas using confidence limit
estimates.

GUIDE FOR THE USE OF THIS HANDBOOK

I. Become acquainted with the laws and regulations.
   A. The Surface Mining Control and Reclamation Act of 1977 established the basic criteria for evaluating mined land revegetation efforts.
   B. The regulations implementing this criteria are found in the Federal Register Vol. 44, No. 50 – Tuesday, March 13, 1979.

II. Develop a scheme for classifying and mapping vegetation and for selecting reference areas and sample sites.
   A. The vegetation classification scheme selected must adhere to established terminology and methods.
      1. Range sites correlate soil and climax vegetation and are used to describe premine reference areas.
      2. Habitat types are based primarily on climax vegetation and secondarily on environmental characteristics and are used to describe premine and reference areas.
      3. Community types are determined according to current vegetation and also describe premine and reference areas.
      4. Response units are based upon similar topographic features, soil texture and depth, and vegetation, and are used to describe croplands, improved pastures, and reclaimed mining lands.
   B. Review the land use terms and the definitions presented by the OSM (Office of Surface Mining).
   C. Know the criteria for the selection of valid reference areas.
   D. Map the vegetation of the premine and reference area using the applicable classification scheme. Map revegetated areas as response units.
   E. Select sample sites that are homogeneous and representative of the area being sampled.

III. Understand the concepts of vegetation sampling.
   A. A random sampling scheme is necessary to obtain a valid estimate of the variance. Simple random sampling or systematic sampling with multiple random starts or random quadrat placement may be used.
   B. The quadrat size and shape will depend upon the type of vegetation being sampled.
   C. Sampling is timed to coincide with the maximum obtainable production value for current year's growth.

IV. Understand the production concepts and definitions used in this handbook. Production must be sampled on all revegetated and reference areas. The methods presented here are to be used unless production is to be compared to a standard. The methods used are then those used in establishing the standard.
   A. The harvest method is the most accurate method. It harvests total production from each quadrat and should be used during the year preceding bond release.
   B. The weight-estimate method requires both estimation and harvesting and may be used in all years except the one immediately preceding bond release.
   C. When grazing (utilization) has occurred before sampling, the amount of grazing (use) must be determined and production must be adjusted back to total production.
      1. The height-weight method for grasses allows estimation of use based upon the nonlinear relationship in grass plants of height to weight.
      2. The amount utilization on shrub plants is extremely difficult to estimate. Rough estimates may be obtained using the relationship of twig length or diameter to twig weight.

V. Become acquainted with cover sampling concepts. Cover must be determined on all revegetated reference areas using one or more of the following methods. If cover is to be compared to a standard, the methods used in determining the standard must be used.
   A. The point-quadrat method uses a point frame and is best suited to herbaceous vegetation below 3 ft (0.9 m) in height.
   B. The line-intercept method allows measurement of aerial cover of plants along a tape measure and is most accurate with grasses or shrubs with rounded canopies.
   C. The 35mm slide method involves photographing sample quadrats in the field and determining percent cover from the developed slide.
   D. Bitterlich's variable-radius method is used for sampling basal area and density of trees. Trees are tallied using an angle gage, optical wedge, or prism, and the probability of tallying any tree is proportional to its stem basal area.

VI. Assess density or stocking rate on revegetated areas that have been planted with shrubs or trees.
   A. Bitterlich's variable-radius method is used for sampling tree density, but is not well suited for small trees.
   B. The density-quadrat method for shrubs and trees requires a total count of all shrubs and trees within the quadrat and may be used on any size class.

VII. Understand the concepts of species diversity and know the important criteria for evaluating each sampling situation. Species diversity will be determined primarily only for wildlife habitat areas. The diversity of the revegetated area will usually be compared to that of a reference area using cover or production data collected according to the methods previously described.
   A. Shannon's Diversity Index provides independent measurements of species diversity for a revegetated area and its reference area based upon

both numbers of species and the evenness of the distribution of individuals among species. Its validity in the comparison of reference and revegetated areas is questionable, and it is recommended that it not be used.

   B. Spearman's Rank Order Correlation Coefficient allows a direct comparison between a reference and a revegetated area of the apportionment of individual species or life forms. However, it can only be used under the constraints described in the text.

   C. Modifications of Sorensen's Similarity Index and Spatz' Index yield a single comparison of both the numbers of species and the evenness of the distribution of individuals among species for a revegetated area and its reference area. They appear to be the most widely applicable measures of diversity for this sampling situation.

   D. The choice of a similarity index must ultimately be based upon the objectives of the investigator.

   E. Importance values reflect a species' overall contribution to a community (that is production or cover) and are used in the calculation of diversity indices and tests. Their selection is discussed in the text.

VIII. Know the statistical requirements stated in the regulations.

   A. A two-stage sampling procedure will be used to insure that the required number of sample observations have been taken for each production, cover, and density sample.

   B. A confidence-limit estimate must be calculated to determine if the revegetated area has 90 percent or more of the production or cover of the reference with the specified level of confidence.

   C. The confidence-limit estimate will tell the investigator how many units (lb/acre or kg/ha) the revegetated area has exceeded or fallen below the requirements stated in the regulations.

   D. The possibility of errors in data collection and analysis should be considered when the statistical tests show that the revegetated area has not achieved 90 percent or more of the production or cover of the reference area.

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INTRODUCTION: LAWS AND REGULATIONS

The Surface Mining Control and Reclamation Act of 1977, Public Law 95–87, established the basic criteria for evaluating successful mine revegetation. The act states that before a mining permit will be issued, a reclamation plan will be filed that includes a statement of:

> the productivity of the land prior to mining, including appropriate classification as prime farm lands, as well as the average yield of food, fiber, forage, or wood products from such lands obtained under high levels of management (Sec. 508.(a)(2)(c)).

The environmental protection performance standards of the act state that the affected land will be restored "to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or to higher or better uses of which there is reasonable likelihood" (Sec. 515.(a)(2)). On all affected lands there will be established:

> a diverse, effective and permanent vegetative cover of the same seasonal variety native to the area of land to be affected and capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area, except that introduced species may be used in the revegetation process where desirable and necessary to achieve the approved post-mining land use plan. (Sec. 515. (b)(19)).

The act mandates the description of the vegetation community prior to mining and after reclamation in order to evaluate revegetation success. Specifically, the act and subsequent interpretations require the measurement and analysis of cover, production, and diversity. The specifications for assessing revegetation success are found in the Rules and Regulations published in the Federal Register Vol. 44, No. 50 – Tuesday, March 13, 1979. Appendix I of this handbook contains a complete copy of those sections pertaining to revegetation. Those sections pertinent to this handbook are as follows:

1. The ground cover and productivity of the revegetated area will be at least 90 percent of that of the reference area, with 90 percent statistical confidence or with 80 percent statistical confidence on shrublands.

2. If revegetation standards specified by a technical guide have been approved pursuant to 30 CFR 816.116 (b)(1), then ground cover and productivity must be at least 90 percent of those standards.

3. Vegetation cover on areas developed for fish and wildlife management or forest land will be at least 70 percent of that of the reference area, with 90 percent confidence.

4. Areas revegetated by trees or shrubs will have a minimum stocking of 450 trees or shrubs per acre (1 125/ha).

5. Permit areas 40 acres (16 ha) or less in size receiving 26 inches (66 cm) or more of annual precipitation will sustain an herbaceous vegetative ground cover of 70 percent for 5 full consecutive years and 400 woody plants per acre (988/ha) after 5 years. On steep slopes (greater than 20 percent), the minimum number of woody plants will be 600 per acre (1 500/ha).

Information on specific situations is in the Rules and Regulations (appendix I). Since the act states that the rules and regulations of individual States must equal or exceed those of the Federal Government, it will also be necessary to become familiar with the rules and regulations of the State of interest.

ELEMENTS OF DELINEATING REFERENCE AND REVEGETATED SAMPLE SITES

Vegetation Classification

A thorough understanding of vegetation type concepts is imperative for implementing good sampling techniques. The delineation of sampling units should be dependent upon the classification of vegetation types, and it is important that a classification be chosen that meets the specific sampling situation. The most frequently used classifications will be defined here, along with a discussion of when they should be used.

"Vegetation type" is a general term that refers, simply, to a plant community with distinguishable characteristics. In mapping vegetation or delineating sampling units, more refined concepts of vegetation communities are generally required. "Range site" and "habitat type" are two closely related terms that have widespread applicability for classifying vegetation communities. A range site, as defined in the Society for Range Management (SRM) Glossary of Terms (1974), is "a distinctive kind of rangeland, which in the absence of abnormal disturbance and physical site deterioration, has the potential to support a native plant community typified by an association of species different from that of other sites. This differentiation is based upon significant differences in kind or proportion of species or total productivity." The U.S. Department of Agriculture's Soil Conservation Service (SCS) and other agencies (such as the Department of the Interior's Bureau of Land Management, State

agencies, universities) have determined the major range sites for those States having large areas of rangeland. The information is available in the form of "range site descriptions" that give the major soil type, precipitation zone, and potential vegetation of the site, as well as a range in species composition at potential and a range in production. The range site concept is useful even in those areas that do not have range site descriptions available; a complete explanation of their use can be found in section 302 of the SCS National Range Handbook (1976). In addition, a classical discussion of range site concepts is available in Dyksterhuis (1949). (A complete listing of the SCS State offices for OSM Region IV is provided in appendix II.)

Steele and others (1979) have presented this version of the classic Daubenmire definition of a habitat type:

A habitat type is all the land capable of producing similar plant communities at climax. The climax plant community, since it is the end result of plant succession, reflects the most meaningful integration of the environmental factors affecting vegetation. Each habitat type represents a relatively narrow segment of environmental variation that is delineated by a certain potential for vegetative development. Although one habitat type may support a variety of disturbance-induced or seral plant communities, the ultimate product of vegetative succession anywhere within one habitat type will be similar climax communities. Thus, the habitat type system is a method of site classification that uses the plant community as an integrated indicator of environmental factors. These factors affect species reproduction, competition, and plant community development.

The climax community type, or association, provides a logical name for the habitat type, for example *Pseudotsuga menziesii/Calamagrostis rubescens*. The first part of this name is based on the climax tree species, usually the most shade tolerant tree species adapted to the site. This level of stratification is called the series and encompasses all habitat types having the same dominant or characteristic undergrowth species in the climax community.

The concepts of range sites and habitat types are very closely related. Historically, range site concepts have been most often used to describe rangeland and grazing land, while habitat types have been used to classify forests and woodland. Range site classification has placed a greater emphasis, perhaps, on correlating soil and vegetation characteristics, while habitat type classification has dealt primarily with those characteristics inherent in the vegetation association, and secondarily with environmental characteristics. Both methods are valuable for the classification and mapping of vegetation.

Both range sites and habitat types describe vegetation communities in terms of their capability to produce a climax or potential vegetation community. They should be used to describe premining areas and natural reference areas that fit into the categories of woodland, grazing land, or rangeland. (Definitions for these categories are given later in this section.)

"Community type" is a term used to describe a vegetation community on the basis of its current vegetation. A community type has certain diagnostic climatic and edaphic features, but the successional status and climax vegetation of a community type are unknown. This term has the same uses as a range site or habitat type.

A delineation that describes most reclaimed mining areas is the "response unit." The climax vegetation of a response unit is unknown. A response unit is an area of land with similar topographic features, soil texture and depth, and vegetation. Response units can be compared by their capability to produce similar amounts and kinds of agricultural crops and pasture plants and to respond in a similar manner to various management techniques. Croplands and improved pastures, as well as revegetated mining land, can be accurately described as response units.

Land Use Terms

For the purposes of this handbook, it is necessary to clarify some definitions. These definitions are presented in the permanent regulatory program for surface coal mining and reclamation operations.

"Cropland" means land used for the production of adapted crops for harvest, alone or in a rotation with grasses and legumes, and includes row crops, small grain crops, hay crops, nursery crops, and orchard crops. Land used for facilities in support of cropland farming operations and which is adjacent to or an integral part of these operations is also included.

"Improved pastureland or land occasionally cut for hay" is land used primarily for the long-term production of adapted domesticated forage plants to be grazed by livestock or occasionally cut and cured for livestock feed. Land used for facilities in support of such use and which is adjacent to or an integral part of these operations is also included.

"Grazing land" includes both grasslands and forest lands where the indigenous vegetation is actively managed for grazing, browsing, or occasional hay production. Land used for facilities in support of ranching operations and which are adjacent to or an integral part of these operations is also included.

"Rangeland" means land on which the natural potential (climax) plant cover is principally native grasses, forbs, and shrubs valuable for forage. This land includes natural grasslands and savannas, such as prairies, and juniper savannas, such as brushlands. Except for brush control, management is primarily achieved by regulating the intensity of grazing and season of use.

"Woodland" refers to an open stand of deciduous or coniferous vegetation where woody vegetation covers approximately 25 to 60 percent of the ground area.

In addition to the "Range Site Descriptions," the SCS has developed for various states "Woodland Suitability Interpretations," which evaluate productive and management problems for woodland soil series and list the trees common to each soil series. "Pasture Suitability Groupings" are also available for certain states and list the best adapted pasture species for each soil series. "Woodland Suitability Interpretations," "Pasture Suitability Groupings," and "Range Site Descriptions" can all be of value to the investigator in classifying vegetation types into range sites, habitat types, or community types. They describe (1) the soils that a particular vegetation community occurs on, and (2) the major plant species that comprise the community (both climax native species and adapted introduced species in the case of Woodland and Pasture Suitability Groupings).

Because the vegetation community is a partial reflection of the soils that underlie it, soils can play an important part in classifying and describing vegetation communities. Although a vegetation community may occur on several soil series, each

soil series is characterized by only one vegetation community. Therefore, a knowledge of the soil series in an area and of their potential natural vegetation can be a tremendous aid in mapping vegetation. Many counties in the United States have published soil surveys that completely map the soil series in the county and give management and cultivation interpretations for each series. These are available from the SCS. In addition, a soil series map is generally required before a mining permit is issued.

Reference Area Selection

Reference areas serve as standards of comparison to assess whether mined land areas have been successfully revegetated. Reference areas are land units maintained under appropriate management for the purpose of measuring vegetation ground cover, productivity, and plant species diversity that are produced naturally or by crop production methods approved by the regulatory authority. Reference areas must be representative of geology, soil, slope, and vegetation in the permit area.

The selection of reference areas will be dependent upon (1) the proposed land use for the revegetated area (wildlife habitat, improved pasture, cropland, and so forth) and (2) the approved revegetation plan for each individual mine. It is recognized that in many cases postmining vegetation and land uses may differ from premining vegetation and land uses. In Region IV of the OSM, an example of this would be the conversion of an oak savanna grazing land to an improved pasture of fescue or bermuda grass. In this case, the reference area would be an improved pasture of fescue or bermuda grass.

Mined and revegetated areas may differ significantly from the communities that originally occupied the site. Perhaps the most important of these, from a biological standpoint, is that the properties of the soil are often altered. The topography of the site may be changed and the composition of the vegetation may or may not be similar to that of the original site. Therefore, when comparing a revegetated area to a reference area, it will be necessary to integrate the factors that characterize the "new site" created through revegetation with those of the preexisting, established reference area. A list of the essential criteria for comparing revegetated and reference areas follows:

1. Individual site factors including elevation, precipitation, slope, and aspect must be the same for both areas.

2. Both areas will be comprised of the same plant life-forms and seasonal varieties of vegetation.

3. Management of the reference area will have to be consistent during the revegetation phase and the same as that proposed for the revegetation area. The condition class of the reference area (when dealing with rangeland) should be the same as that desired in the management plan for the revegetated area and should have a stable trend.

4. Although it is unlikely that the revegetated area will have the same soils as the reference area, it is important that certain edaphic characteristics be similar.

5. The reference area will have to be realistically comparable to the revegetated area, having the capability to produce a similar kind and amount of vegetation.

It is not essential that the reference area be immediately adjacent to the revegetated area as long as the above criteria are met. The two areas must not be separated by too great a distance, however, as differences in rainfall distribution patterns and other environmental factors could result in statistically different production, cover, and diversity values.

Reference areas for croplands should be a minimum of 1 acre (0.4 ha) in size. Larger areas of 2 to 5 acres (0.8 to 2 ha) are preferable, however, as they allow for variations in productivity due to differences in nutrient availability, topography, drainage, and so forth.

When the postmining land use of an area is grazing, special measures will have to be taken to ensure that past grazing has no effect on the accuracy of production, cover, and diversity sampling on either the revegetated area or the reference area. This can be accomplished in one of three ways:

1. Exclosures could be built on both the revegetated area and the reference areas to exclude livestock grazing during the years in which sampling is to occur. Exclosures should be a minimum of 1 acre (0.4 ha) in size on improved pastures and from 2 to 5 acres (0.8 to 2 ha) on grazing land and rangeland.

2. Grazing could be deferred or delayed on both the revegetated and reference areas until after sampling has been completed. The deferment applies only to those years during which sampling is scheduled. The proposed grazing management scheme should be adhered to during all other years.

3. Utilization correction factors could be used to adjust production figures if sampling occurs after livestock grazing, and cover values could be determined from basal instead of aerial values. These methods are detailed in production and utilization sections of this handbook.

Special consideration is required in the selection of reference areas for mined lands that are to be revegetated as wildlife habitat areas or that are to approximate the potential natural vegetation (woodland, rangeland, or grazing land). Areas must be chosen that are consistent with the management goals or the planned future use of the area. They must also be representative of the potential natural community as described by range site or habitat type concepts. Where differences in species composition exist between the potential natural community and the revegetated area, life-form and seasonality must be similar.

Vegetation Mapping

The actual classification and mapping of vegetation is best performed on the ground with the aid of aerial photographs. The criteria used for mapping vegetation units on both revegetated and reference areas include all of the elements previously discussed under vegetation types: soils, vegetation, and topography. The initial classification is done on the basis of similarities in plant species, the amount of vegetation produced, and the relative proportions of the individual species. SCS "Range Site Descriptions" and "Woodland Suitability Groupings" are helpful in distinguishing the differences between various range sites and habitat types.

Soil survey maps can be used to refine the boundaries between vegetation units. Although soil lines often coincide with vegetation unit boundaries, they should not be the sole basis for mapping vegetation. Individual characteristics of the vegetation community, such as production and species composition, must also be considered. In addition, there may be transition zones between the vegetation units that the plant scientist wishes to interpret differently than does the soil scientist.

The topographic features of aspect and slope are also important considerations because of their potential influence on vegetation communities. South and west slopes should generally be mapped separately from north and east slopes.

Aerial photos on the scale of approximately 1:20,000 (3.16 inches/mile or 8.03 cm/km) are normally the most convenient for this type of work. However, the scale will be determined by the intensity of mapping that is desired. A table of scales and equivalents for maps and photographs is provided in appendix III. Sheets of mylar (a clear plastic film) can be used to overlay individual photos for the mapping of soils and vegetation. A summary of all cartographic-related information sources compiled by the National Cartographic Information Center (NCIC) is in appendix IV. Bureau of Land Management Technical Note 287, ''The Use of Aerial Photographs'' and Eugene Avery's text, ''Interpretation of Aerial Photographs,'' may prove useful to the reader.

Another essential tool for vegetation and soil mapping is the topographic map. An index to topographic maps of individual States as well as standard quadrangle maps published in the 7.5- or 15-minute series can be obtained from the Branch of Distribution, U.S. Geological Survey, 1200 South Eads Street, Arlington, VA 22202. In addition, a bibliography on ''Selected Books on Maps and Mapping'' by the USGS is included in appendix V.

Sample Site Selection

The selection of a sample site is made after the vegetation classification has been decided, mapping has taken place, and a reference area has been chosen. The sample site must be a homogeneous area that accurately represents the range site, habitat type, community type, or response unit being selected. The sample must be taken in a pure vegetation type and not in transition zones between adjacent types. The sample site should be located so it avoids the effects of neighboring vegetation types, roads, stream courses, and so forth.

The area selected as a sampling site must be large enough to obtain an adequate sample. A minimum sample unit of 2 to 5 acres (0.8 to 2 ha) is recommended for sampling reference areas; however, a larger area may be desirable for sampling rangeland and woodland. When evaluating revegetated areas, the entire area must be sampled. It may be desirable to stratify the area on the basis of major topographic features, soil conditions, or other major site conditions that may have a significant effect on vegetation characteristics.

CONCEPTS OF VEGETATION SAMPLING

Vegetation sampling is a means by which an investigator can make inferences about a plant community based on information obtained from intensive examinations of a small proportion or sample of that community. A true characteristic of the plant community is a parameter such as cover, production, or diversity, while an inferred characteristic is a statistic of that parameter. In vegetation sampling, we are concerned with inferring the true characteristics based on parameter statistics that are felt to represent the plant community. The importance of developing a sampling scheme that closely approximates the actual parameters of a community cannot be overemphasized, especially when dealing with small confidence intervals. It is critical that the sampling methods used be both precise (or repeatable) and accurate (or capable of delineating the true characteristics of the community).

It is very important that the sample provide an unbiased estimate of the variance and the mean of the parameters being studied. There has been a considerable amount of discussion in the sampling literature concerning the relative merits of random and systematic sampling. A simple random sample gives each individual in the population an equal chance of being selected that is independent of the chance of any other individual being selected. The estimate of the variance and the mean of the population is unbiased and consistent, and provides a valid basis for computing the estimate of its sampling error. A simple random sampling scheme may be, however, somewhat time-consuming to devise and execute in the field.

A systematic sample usually has one or more random starts and consists of a number of mechanically spaced sample plots along one or more transects. A systematic sample provides an unbiased and consistent estimate of the population mean and is often more time and cost efficient than a simple random sample. Systematic schemes are relatively easy to draw and to execute in the field. However, unless more than one random start is used, they do not provide enough information for computing an exact sampling variance. To insure obtaining an unbiased estimate of the population mean and a valid basis for computing the estimate of its sampling error, the methods presented in this handbook incorporate simple random sampling or systematic sampling with multiple random starts or random quadrat placement.

Cook and Bonham (1977) state that the ''selection of a sample will depend upon: (a) the features of the population, (b) the variation among individuals, (c) the inferences to be made concerning the population, and (d) labor and time involved in collecting data.'' Each of these factors deserves critical consideration when choosing the proper sampling method. The concepts and methods explained in this handbook were chosen for their accuracy and precision. No attempt is made to review all of the various sampling methodology available, although the inherent weaknesses in certain techniques and the logic in choosing one technique over another is discussed. Several recent reviews and manuals of vegetation measurement techniques are available to the interested reader: Pieper (1973), Cook and Bonham (1977), Bonham and others (1980), and Knight (1978). Texts also of use include L. 't Mannetje (1978), Mueller-Dombois and Ellenberg (1974), Greig-Smith (1964), and Joint Committee of the American Society of Range Management and the Agricultural Board (1962). U.S. Department of Agriculture and U.S. Department of the Interior manuals that are available include the SCS National Range Handbook (1976), BLM Manual 4412.14, Soil-Vegetation Inventory Method (1979), and Forest Service Handbook 2209.21, Range Environmental Analysis (1968).

All terminology in this handbook adheres to the Society of Range Management (SRM) glossary of terms and the definitions in the permanent regulatory program for surface coal mining and reclamation operations.

Random Sampling Schemes

The sampling schemes outlined here—random, stratified random, and systematic sampling with multiple random starts—allow the calculation of a valid estimate of the variance of the mean. The specific scheme chosen depends on the parameter under investigation and on the sampling methodology used. Convenience, ease of implementation, and cohesiveness with the sampling methodology should be considered when deciding upon which scheme to use.

GENERAL CONSIDERATIONS

It is imperative that all sample points be objectively located within the sample unit. Knight (1978) states that three rules should always be followed:

1. Sample points should be distributed throughout the sample units and not just within a small portion of the sample unit.

2. Sample points should be located without any bias of the investigator.

3. Sample points should be located far enough within the sampling unit to avoid transition zones and the edge effect created by highways, rivers, and so forth.

The objective selection of random sample points is best accomplished with the use of a random numbers table.

USE OF RANDOM NUMBERS TABLES

A random numbers table is presented in appendix VI. Its use is outlined as follows:

1. An arbitrary, objective starting point is selected anywhere on the table, as long as it is not chosen because of the size of the number at that point.

Each digit within a random numbers table is a random number although random numbers are often given as four digits. If the bottom of column 2 in appendix VI were selected as a starting point, 4067, 406, 40, or 4 could be used as the first random number. The units of measure used for locating the sample points (paces, m, dm, and so forth) will determine the size of the number selected. The same sequence of numbers should always be selected, and zeros should be counted as one of the digits.

2. All subsequent random numbers are selected in the same manner as the first, progressing in order down the column.

RANDOM SAMPLE POINT LOCATION

The location of random sample points is depicted in figure 1.
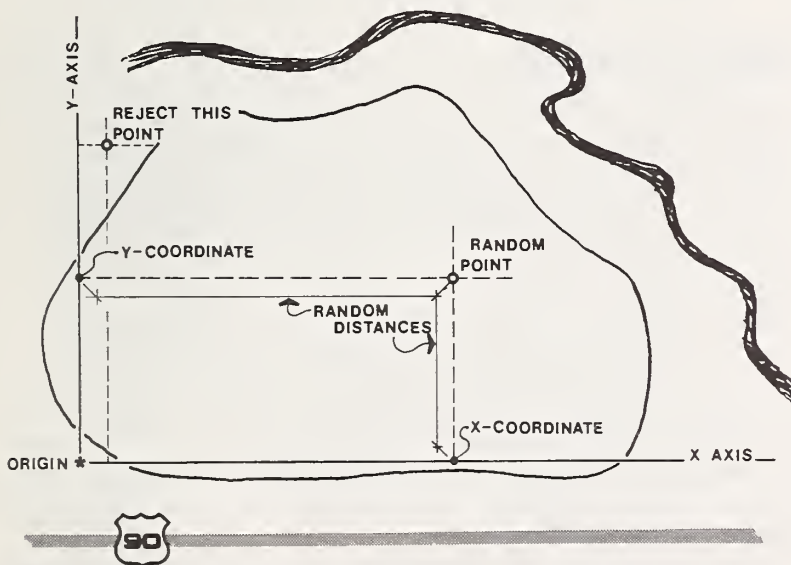
Figure 1.—Random sample point location
(from Knight 1978).

The procedures for selecting random sample points are as follows:

1. Select two random numbers as described under the section on use of random numbers tables. The first number chosen is used as the distance along the x-axis and the second as the distance along the y-axis.

2. Locate the x-coordinate by pacing or measuring the random number distance along the x-axis from the point of origin. From the x-coordinate, pace or measure a line perpendicular from the x-axis and equal to the random number distance along the y-axis. The point at the end of the line is the random sampling point. A perpendicular line from the y-axis to the random sampling point should equal the distance along the x-axis. A sample point that falls outside of the sampling unit is not used.

3. Return to the point of origin, select the next two random numbers, and repeat the process described above. Continue this process until all sample points have been taken.

STRATIFIED RANDOM METHOD USING A BASELINE

The procedure for locating random sampling points using a baseline is shown in figure 2.
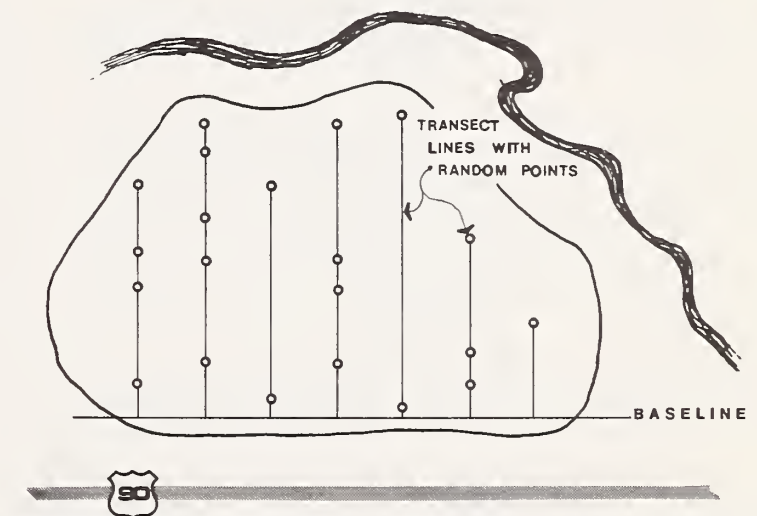
Figure 2.—Stratified random method using a baseline (from Knight 1978).

1. Locate a baseline either through the middle or along one edge of the sampling unit. Points along this line will be spaced a predetermined and equal distance apart, such as 100 ft (30 m).

2. Proceed to the first point on the baseline and select a random number. This number is the distance to the first sample point along a line running perpendicular to the baseline. When the baseline is in the middle of the area and the random number is even, the sample point is on the right; if it is odd, the sample point is on the left.

3. Point 2 is obtained by choosing a second random number that is the distance to point 2 from point 1 along the same perpendicular line. Additional points are located in the same manner until the perimeter of the stand is approached. The investigator then returns to the baseline and proceeds to the second predetermined point. Sample points are then located along a line perpendicular to this point as described above. The procedure is repeated until an adequate sample has been collected.

Random numbers that result in the overlap of sample plots should be disregarded in most sampling situations. An occasional overlap of plots when using Bitterlich's variable radius method or the density quadrat method for shrubs does not decrease the validity of the data.

SYSTEMATIC SAMPLING WITH MULTIPLE RANDOM STARTS

Systematic sampling with multiple random starts is an efficient method of locating sample points that still allows a valid calculation of the variance of the mean, even though it utilizes systematic sampling (see Shiue 1960). This method can be implemented using a baseline and is similar to the stratified random method shown in figure 2. The procedures for establishing sample points using this method are as follows:

1. Locate a baseline either through the middle or along one edge of the sampling unit. Points along this line will be spaced a predetermined and equal distance apart.

2. Proceed to the first point on the baseline and select a random number. The random number is the distance to the first sample point along a line running perpendicular to the baseline (transect line).

3. Locate subsequent points a predetermined and equal distance apart along the transect line. Discontinue sampling along the transect line when the perimeter of the sample unit is approached.

4. Return to the baseline and proceed to the second predetermined point. Sample points are located along the transect line perpendicular to this point as described above. The distance to the first sample point is once again determined by the selection of a random number. Continue in this manner until an adequate sample has been taken, and the entire sample unit has been sampled.

If the baseline is placed in the middle of the sample unit, transects are placed on both sides of the baseline. A minimum number of random starts is six, but more are preferred.

Quadrat Size and Shape

Selecting the proper plot size and shape is very important for efficient sampling or sampling that will minimize both variance and sampling time. After reviewing the literature, Van Dyne and others (1963) presented the following generalizations concerning the influence of plot size and shape:

1. Perimeter-to-area ratios are lowest in circular plots and decrease as plot size increases. Low perimeter-to-area ratios generally decrease sampler error.

2. More species generally are included in long, narrow plots.

3. Optimum plot size and shape may depend upon the distribution of the species measured, with larger plots usually recommended in sparse vegetation.

4. Small sampling units, although generally more efficient statistically, often yield skewed data, and thus may not accurately represent the true population.

5. Greatest efficiency is generally indicated by smallest variance.

6. Random plot location is necessary for an unbiased estimate of variance.

7. To obtain an estimate of sampling error, an exclosure should contain more than one plot.

Both the type of vegetation community being sampled and the parameters being investigated will determine not only the plot size and shape, but also the specific methodology used. Table 1 presents the generalized vegetation types found in OSM Region IV and suggested quadrat sizes and shapes for use in each.

Table 1.—*Quadrat sizes for sampling production with circular, square or rectangular quadrat frames*

Vegetation type	Metric measure	American measure
Dense[1] tall-grass prairie and pastures	0.25–0.75 m²	0.96–2.40 ft²
Sparse[2] tall-grass prairie and pastures	.50–1.50 m²	1.92–4.80 ft²
Woodlands-dense understory	.75–1.50 m²	2.40–4.80 ft²
Woodlands-sparse understory	1.00–2.50 m²	4.80–9.60 ft²
Dense mid-grass prairie	.25–0.75 m²	.96–2.40 ft²
Sparse mid-grass prairie	.50–1.50 m²	1.92–4.80 ft²
Dense shrublands	.75–1.50 m²	2.40–4.80 ft²
Sparse shrublands	1.50–2.50 m²	4.80–9.60 ft²

[1]Dense is defined as ≥ 50% aerial cover.
[2]Sparse is defined as < 50% aerial cover.

Quadrat Sizes and Conversions

To convert grams per quadrat to pounds per acre:
On 0.96 ft² quadrats, multiply grams by 100
On 1.92 ft² quadrats, multiply grams by 50
On 2.40 ft² quadrats, multiply grams by 40
On 4.80 ft² quadrats, multiply grams by 20
On 9.60 ft² quadrats, multiply grams by 10

To convert grams per quadrat to kilograms per hectare:
On 0.25 m² quadrats, multiply grams by 40
On 0.50 m² quadrats, multiply grams by 20
On 0.75 m² quadrats, multiply grams by 13.33
On 1.00 m² quadrats, multiply grams by 10
On 1.50 m² quadrats, multiply grams by 6.67
On 1.00 m² quadrats, multiply grams by 5
On 2.50 m² quadrats, multiply grams by 4

Kilograms per hectare × 0.89235 = pounds per acre
Pounds per acre × 1.12064 = kilograms per hectare

Time of Sampling

In cases where sampling is intended to reflect the peak or maximum productivity, sampling should be timed to coincide with the seed-ripe or mature phenological stages of the majority of the species under investigation. At this stage the plants have accumulated the greatest biomass, and yield the highest amount of production.

Because the purpose of the sampling methodology described here is to compare two areas similar in life-form and seasonality, it is logical to obtain this comparison by sampling both areas during the same time interval and when the majority of the species are at the highest level of production. The sample does not necessarily need to reflect the *total* year's growth (production) of the community.

Numerous plant communities exist in which there is significant difference between the timing of flowering and seed production of the major species. Two examples of this are communities with both cool-season (perennial ryegrass) and warm-season (little and big bluestem) grasses, and communities with grasses that flower and mature long before the shrubs. Cool season plants generally make the major portion of their growth during the winter and early spring, and warm season

plants make most or all of their growth during the spring, summer, or fall and are usually dormant in winter. In communities with varying seasonality, it may be necessary to sample when overall community production is at a peak. For the community with both cool-season and warm-season species, this would be at some point after which the cool-season grass had matured, but before it had dropped its seed. The warm-season grasses would likely be approaching maximum foliar growth and nearing anthesis or flowering. If the periods of peak production of the major species are extremely disparate, it may be desirable to sample at two different times to obtain an accurate estimate of total maximum productivity.

In some cases, it may be necessary to stagger sampling times between revegetated areas and reference areas, especially if the species are dissimilar and have different maturation times and phenologies. Each area must be sampled when the majority of its species are in the seed-ripe or mature phenological stages.

If the investigator wishes to obtain a value of total years production for the year, a separate phenological study can be initiated. This would involve sampling both areas at specified intervals (say, 2 weeks) throughout the growing season and collecting data on the dry-weight production of each species during each of its phenological stages. A method based upon this concept is described in BLM Manual 4412.

PRODUCTION SAMPLING CONCEPTS

Several definitions and various interpretations are available for the parameters of production, cover, and diversity. The definitions presented here were chosen to comply with the OSM regulations and to allow for the most efficient and accurate sampling and subsequent comparison of revegetated and reference areas.

Ideally, the vegetation investigator would sample net primary production, or the net increase in plant biomass (total energy content), which is incorporated into the aerial parts of the plant community within a specified area and time interval. Net primary production is very difficult to collect, however, and for the purposes of this handbook a simpler definition of production will be used that still provides accurate comparisons. The definition adhered to here is:

"Vegetation production" is the current year's plant growth that consists of all green leafy vegetation, flowering stalks, seed-heads, and stems of herbs, and all green leafy vegetation, flowers, seeds and current year's twig growth of shrubs and trees. It also includes the persistent green, living leaves of evergreen species.

This definition does not apply when a revegetated area is compared to an approved standard. Such a comparison will require that the revegetated area be harvested or sampled in the same manner as the standard. It will be necessary to duplicate the exact methodology and to adhere to the same units of measure (bushels/acre or tons/acre) used to establish the standard if a valid comparison is to be made.

When the revegetated and reference areas have similar species composition and production data are to be used in the measurement of diversity, production should be sampled according to species. If the revegetated and reference areas differ in species composition, the production should be sampled by life-form. Table 2 presents the suggested life-form categories.

Table 2.—*Hierarchial life-form classification*

I. Grasses and grasslike
A. Annual
B. Perennial
1. Rhizomatous
a. Warm-season
b. Cool-season
2. Bunch
a. Warm-season
b. Cool-season
II. Herbs
A. Annual
B. Perennial
C. Biennial
III. Shrubs and halfshrubs
A. Broadloaf
1. Deciduous
2. Evergreen
B. Needleleaf
1. Deciduous
2. Evergreen
IV. Trees
A. Broadleaf
1. Deciduous
2. Evergreen
B. Needleleaf
1. Deciduous
2. Evergreen
V. Lichens and mosses

For the purposes stated within this handbook, production will be measured at only one point in time.

Several standards need to be conformed to when obtaining production samples:

1. All production samples will be converted to dry weights and should be ovendried at 140° to 158° F (60° to 70° C). In areas characterized by high relative humidities, ovendrying is necessary to prevent wide fluctuations in dry weights and to obtain reliable, repeatable data.

2. Because production as defined here includes only current year's growth and living green leaves, it will be necessary to separate and remove all dead plant material not produced during the current growing season.

3. In order to standardize sampling and minimize sampler error, all vegetation will be harvested to ground level. If the production data are to be used for animal unit month (AUM) calculations, normal grazing height can be accounted for through proper use. Proper use is a degree and time of use of current year's growth that, if continued, will either maintain or improve pasture or range condition consistent with management goals.

4. Reference areas and revegetated areas will be sampled when the majority of the species have mature seeds.

PRODUCTION SAMPLING METHODOLOGY

The methods here will provide investigators with the most reliable results and will allow them to meet the statistical limits

required in the regulations. Either the harvest method or the weight-estimate method may be used in years prior to bond release; however, during the final year of sampling before bond release, the harvest method should be used. The quadrat size and shape will be determined by the vegetation type (see table 1). An explanation of how to determine the proper number of quadrats will be given in the section on statistics. Quadrat placement within the sampling unit should follow one of the three schemes outlined in the section on random sampling schemes.

Harvest Method

The harvest method involves clipping to ground level all of the vegetation within each quadrat by species or life-form. The procedures used are valid for both the harvest method and for double sampling. An example data form is shown in figure 3. The methods used are as follows:

1. The quadrat is placed on the ground within the sampling unit using a random sampling scheme. The orientation of square and rectangular quadrats must remain constant at each sampling location.

2. The vegetation within the quadrat is clipped to ground level using hand shears or clippers. Vegetation production, as defined earlier, is harvested from the three dimensional volume of the quadrat (height × width × length). Parts of plants that are rooted within the quadrat but do not occupy space within the volume are not harvested, while plants that are not rooted within the quadrat but overlap into the volume are harvested (see fig. 4). The volume method is generally accepted as the most accurate method for production clipping. However, in tall grass swards including only those plants rooted within the quadrat, regardless of quadrat volume, may be more efficient.

3. Vegetation is separated by species or life-form (see table 2), placed in paper bags, weighed, and labeled according to date, sampling unit, quadrat number, weight, and species or life-form. Green weights of species are necessary if sample size is to be calculated in the field and/or if double sampling is used. Phenological stage should be recorded by species if standing crop production is to be adjusted to peak annual production. Standard phenological stages are: (1) Beginning Growth, (2) Vegetative Stage, (3) Boot Stage (grass and grasslike), (4) Peak Flowering, (5) Soft Dough (grass and grasslike), (6) Seed Ripe, (7) Mature, (8) Dormant, and (9) Regrowth.

4. The vegetation samples are ovendried at 140°to 158° F (60°to 70° C) until a constant weight is obtained. Dry weights are then recorded by species or life-form for each quadrat. Weighing should be performed immediately after ovendrying to avoid absorption of water from humid air.

5. Total production and subsequent statistical computations are based upon the dry weights obtained in step 4. The calculations for production and percent composition of individual species or life-forms are:

Site Name _____ Data Sheet No. ____ of ____

Date _____ Location _____

Quadrat size _____ Investigators _____

SEC _____
TWP _____
RNG _____

Species or Life Form	PS	Quadrat Number																						Sheet Total	
		1		2		3		4		5		6		7		8		9		10		11			
		G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D	G	D

REMARKS: _____

PS = phenological stage, G = green-weight, D = dry-weight

Figure 3.—Data form for the harvest method.

8

Figure 4.—Volume projection of a sample quadrat. Record only the weights of portions of plants inside the imaginary cylinder.

$$\text{Production} = \frac{\text{Total of dry weight values}}{\text{Total number of quadrats sampled}} \times \begin{array}{l}\text{Quadrats per area}\\\text{conversion factor}\end{array}$$

$$\text{Percent composition} = \frac{\text{Production for species or life form}}{\text{Total production for all species or life forms}} \times 100$$

Double-Sampling by the Weight-Estimate Method

Double-sampling using the weight-estimate method entails estimating vegetation production in a majority of the quadrats sampled and both estimating and harvesting production in the remainder of the quadrats sampled. This method allows the estimates of all the quadrats sampled to be corrected or adjusted for estimator error by techniques such as regression. Although this method may lack some of the precision and accuracy obtainable through the harvest method, it increases sampling efficiency or decreases the time and cost involved in sampling, especially when it is desirable to obtain production values by species. The increase in sampling efficiency may subsequently permit the sampling of a larger number of quadrats.

If the investigator chooses double sampling by the weight-estimate method, certain precautions need to be taken.

Estimators require considerable training and must constantly check the accuracy of their own estimates if reliable data are to be obtained. There is some indication that estimates may generally be higher than actual values for quadrats with small yields and lower than actual values for quadrats with large yields. This means that the relationship between the estimated and actual clipped weights is probably linear only to a certain weight limit. This weight limit may be in the range of 100 to 120 grams per area of quadrat (Bonham and others 1980). It may therefore be advisable to use smaller quadrats when using the weight-estimate method.

Probably the most reliable method of weight estimation involves the consistent use of weight-units. The weight-unit consists of a representative part of the vegetation being sampled, such as a bunch of grass or a branch of a shrub. Two closely comparable weight-units of the same species are selected and the vegetation production of one is stripped or removed, weighed, and recorded. The remaining unit is then used as a comparison for counting the number of similar units within the sampling quadrat. The number of estimated units within the quadrat is multiplied by the recorded weight of the production removed from the stripped weight-unit to obtain the total estimated green weight. This procedure is repeated for each species in the quadrat. The same weight-units can be used in every quadrat as long as they represent the same growth form.

Estimators must be trained in the techniques of weight estimation. This involves clipping and weighing species within practice quadrats immediately after the entire quadrat has been estimated, and then adjusting individual estimation techniques. Ideally, an estimator would be within 10 percent of the actual clipped value for each species.

The procedural steps used for double sampling by the weight-estimate method are identical to those outlined under the harvest method except for the following differences:

1. The green-weight production within all quadrats is estimated prior to harvesting. An example of a data form for the weight-estimate method is shown in figure 5.

2. The numbers of the quadrats to be clipped are chosen from a random numbers table.

3. Exact quadrat locations should be marked and flagged after estimation so that they can be returned to for clipping. Vegetative material not included within the quadrat should be trimmed away from the quadrat frame in order to make quadrat relocation easier.

4. Species not included within the clipped quadrats but encountered within the estimated quadrats should be clipped from quadrats in which they do occur so that dry-weight conversion and estimator-error correction factors can be obtained.

5. To insure consistency and prevent bias, all quadrats within a sample should be estimated by the same person. The estimator should not be allowed to see the clipped weights of any quadrats within the sample until all plots have been estimated.

The calculations for deriving dry-weight production values from weight-estimate data are more involved than those for harvest data. The estimated green-weight values are corrected for estimator error and then adjusted to dry-weight values.

Two methods are available that use the actual and estimated green-weight values to adjust for estimator error. The first method derives a correction factor for each species by dividing the summed actual clipped weights by the summed estimated weights of the corresponding quadrats.

$$\text{Correction factor} = \frac{\Sigma \text{ clipped weight}}{\Sigma \text{ estimated weights}}$$

The correction factor is multiplied by the individual species value for each quadrat, or by the total species value summed for all of the quadrats.

A second method involves the use of regression to obtain a predictive equation from which estimated weights can be adjusted. Individual species green-weight values for each quadrat, or individual quadrat values summed for all species, can be used for the clipped quadrats and their corresponding estimated quadrats. While the use of quadrat values summed for all species is not as accurate as the use of individual species values, it may, however, be difficult to obtain an adequate sample number for a regression for each individual species. In addition, calculating regressions for each species could potentially be time consuming.

An example given by Pieper (1973) is expanded upon here to illustrate the calculations involved. The estimated weights are

Site Name _____   Data Sheet No. ____ of ____

Date _____ Location _____

Quadrat size _____ Investigators _____

SEC _____
TWP _____
RNG _____

		Quadrat Number (circle clipped quadrats)																									Clip # ___			Clip # ___		
		1					2					3					4					5											
Species	PS	G	CF	A	%D	D	G	CF	A	%D	D	G	CF	A	%D	D	G	CF	A	%D	D	G	CF	A	%D	D	G	D	%D	G	D	%D

REMARKS: _____

PS = phenological stage, G = green-weight, CF = correction factor, A = adjusted green-weight, %D = percent dry-weight, D = dry-weight

Figure 5.—Data form for the weight-estimate method.

considered the independent variable (X) and the clipped weights are considered the dependent variable (Y). In this example, every five quadrats were estimated, clipped, and weighed:

Estimated weight (g)	Actual clipped weight
90	---
75	---
110	---
65	---
40	60
100	---
120	---
60	---
75	---
115	120

and so forth

The pairs of actual and estimated weights obtained are shown in table 3, where X^2, Y^2, and XY are given.

Table 3.—*Clipped (X) and estimated (Y) production values and corresponding values of X^2, Y^2, and XY*

	(clipped) X	X^2	(est.) Y	Y^2	XY
	60	3,600	40	1,600	2,400
	120	14,400	115	13,225	13,800
	100	10,000	95	9,025	9,500
	65	4,225	75	5,625	4,875
	95	9,025	80	6,400	7,600
	60	3,600	75	5,625	4,500
	100	10,000	110	12,100	11,000
	95	9,025	120	14,400	11,400
	85	7,225	60	3,600	5,100
	90	8,100	75	5,625	6,750
	120	14,400	115	13,225	13,800
Σ	990	93,600	960	90,450	90,725
Mean	90		87		

The first step is to calculate the corrected sums of squares and products. The corrected sum of squares for X:

$$\Sigma x^2 = \overset{n}{\Sigma} X^2 - \frac{(\overset{n}{\Sigma}X)^2}{n}$$

$$= 90,450 - \frac{(960)^2}{11}$$

$$= 6,668$$

The corrected sum of squares for Y:

$$\Sigma y^2 = \overset{n}{\Sigma} Y^2 - \frac{(\overset{n}{\Sigma}Y)^2}{n}$$

$$= 93,600 - \frac{(990)^2}{n}$$

$$= 4,500$$

The corrected sum of products:

$$\Sigma xy = \Sigma (XY) - \frac{(\Sigma X)(\Sigma Y)}{n}$$

$$= 90,725 - \frac{(990)(960)}{11}$$

$$= 4,325$$

The equation for a straight line is $Y = a + bX$. Use of the equation requires the assumption of a linear relationship between estimated weights and clipped weights. In the equation, a and b are constants or regression coefficients that must be estimated. According to the principle of least squares, the best estimates of these coefficients are:

$$b = \frac{\Sigma XY}{\Sigma x^2}$$

$$= \frac{4,325}{6,668}$$

$$= 0.65$$

$$a = \overline{Y} - b\overline{X}$$

$$= 90 - 0.65(87)$$

$$= 33.4$$

These estimates can be used in the general equation to obtain

$$Y = 33.4 + 0.65X$$

By substituting the estimated weights for x, a predicted or adjusted value can be obtained for each quadrat or species. This value will be used in all subsequent mathematical computations.

UTILIZATION SAMPLING

Utilization or use is defined in the SRM Glossary of Terms as "the proportion of current year's forage production that is consumed or destroyed by grazing animals." If utilization has occurred before sampling, it will be necessary to adjust the harvested or estimated production figures to their original values before grazing. Several methods have been developed to measure utilization, but the majority have been developed for grass species (see Pieper 1973). Although this information is equally valuable for shrub species, shrubs have been largely neglected due to the difficulties involved in finding suitable methodology for measuring utilization of their heterogenous growth form.

The estimation of percent utilization for grasses, forbs, or shrubs introduces additional error into the final production values obtained. The use of exclosures or the deferment of grazing until after sampling would eliminate this source of error in areas grazed by livestock.

Included here are a height-weight method for use with grasses and forbs, and, for shrubs, a discussion of the method of twig diameter and length of twig removed.

Height-Weight Method for Grasses

One of the most frequently used methods for determining percent utilization is based upon height-weight relationships. This method requires that the relationship between the amount of height removed and the corresponding amount of weight removed be determined for the grass and forb species under study. As shown for black grama in figure 6, this is seldom a linear relationship in grasses because the majority of the weight of a grass plant is at the base of the plant in its basal leaves.
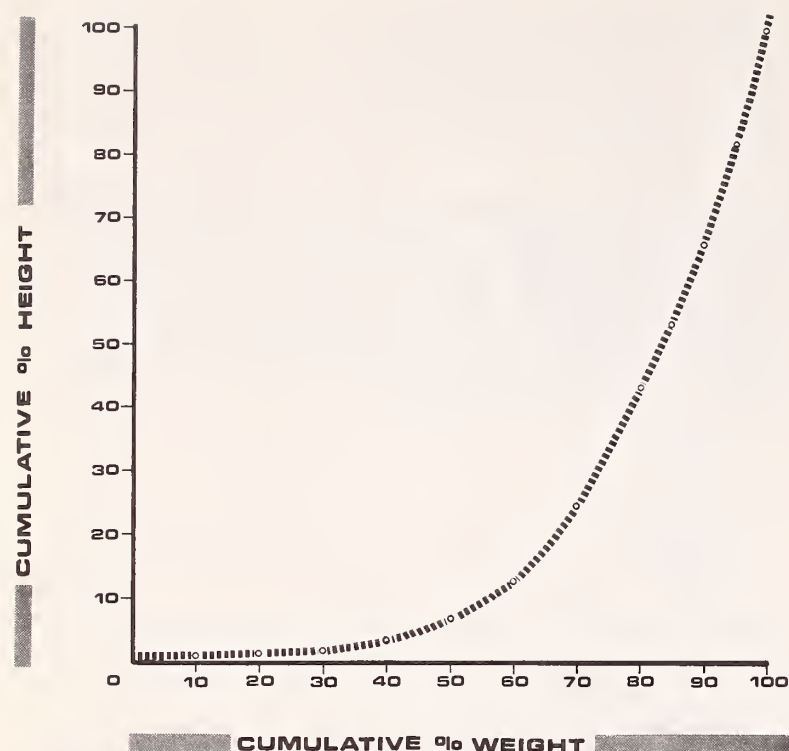
Figure 6.—Height-weight relationship for a 22-inch black grama plant (from Pieper 1973).

Extreme variation can exist in the height-weight relationships of different species of forbs.

The necessary height-weight relationships for the various species must be determined from ungrazed plants before sampling. This can be done in the field as a training excercise for estimators, and if desired, a table of height-weight relationships similar to table 4 can be constructed. For training individuals to estimate percent utilization, cumulative percent height and cumulative percent weight give the most relevant height-weight relationships.

If it is known that grazing will precede sampling, cages should be installed to protect a sufficient number of plants for determining height-weight relationships and for training estimators. The general procedure for determining height-weight values is to clip a number of plants (say, 10) into 1- or 2-inch

(2.5- or 5-cm) segments either in the field or in the lab. If the plants are taken into the lab, a convenient method for grasses is to tie individual plants with string at the desired increments and clip them at ground level. After the individual increments have been separated and weighed, the height-weight relationships are determined. This information is used by the estimator to determine the percent of utilization by species for each individual sampling quadrat. If the harvest method is used, percent utilization must be estimated and recorded before clipping. When the weight-estimate method is used, production is estimated on the basis of the amount of vegetation material in the quadrat at the time of estimation. Adjusted total production values are calculated from estimated or clipped green-weight values and percent utilization.

$$\text{Adjusted total production} = \frac{\text{Estimated or clipped weight}}{\text{100-percent utilization}}$$

Percent utilization is determined on a green-weight basis, and the calculation of adjusted total production precedes the computation of predicted or adjusted green weight and dry weight.

Shrub Utilization

Statistically reliable techniques for correcting sampled shrub production to total production after utilization currently do not exist. The following section discusses methods that have been used, their weaknesses, and their application to sampling of revegetated and reference areas.

The majority of the literature on utilization of shrub species has dealt with developing methods for determining the percent use of the most recent twig growth, or leaders, of the key browse species utilized by big-game ungulates and livestock. Strong correlations exist between twig diameter and weight and length (Smith and Urness 1962; Basile and Hutchings 1966; and Jensen and Urness 1980). If the relationship between twig diameter and weight or twig length and weight is known, it is possible to determine the percent utilization by weight from (1) twig tip diameter, basal diameter, and browsed-tip diameter, or (2) the original leader length and the leader length after browsing. The problem with using twig reduction methods as an index to utilization is that leaves that are removed from other portions of the plant, and twigs that are stripped but not

Table 4.—Height-weight relationship of a 22-inch black grama plant on the college ranch (Pieper 1973)

Height	Increment	Weight	Height	Cumulative height	Weight	Cumulative weight
------- Inches -------		Grams	------------------- Percent -------------------			
19.8–22.0	2.2	0.2	0.10	10	0.32	0.32
17.6–19.8	2.2	.4	10–20	20	.63	.95
15.4–17.6	2.2	.6	20–30	30	.95	1.90
13.2–14.4	2.2	1.0	30–40	40	1.58	3.48
11.0–13.2	2.2	2.0	40–50	50	3.17	6.65
8.8–11.0	2.2	3.8	50–60	60	6.02	12.67
6.6–11.0	2.2	7.5	60–70	70	11.88	24.55
4.4–6.6	2.2	11.6	70–80	80	18.37	42.92
3.3–4.4	1.1	6.2	80–85	85	9.82	52.74
2.2–3.3	1.1	8.1	85–90	90	12.83	65.57
1.1–2.2	1.1	10.2	90–95	95	16.16	81.73
0–1.1	1.1	11.6	95–100	100	18.22	99.95
	22.0	63.1			99.95	

removed, are not taken into account. The relationship between twig diameter and weight and length varies greatly among species, and it is necessary to develop separate regressions for each species.

If the investigator does find it necessary to adjust for shrub utilization, the twig diameter or length of twig removed methods for shrubs can be used. For detailed descriptions of these methods, refer to the above literature citations. The generalized procedures for this particular sampling situation are given here.

Regression equations in which twig diameter or twig length was the independent variable and twig weight was the dependent variable would be developed by species. It may be possible to obtain the required measurements for developing the regressions from ungrazed twigs or leaders. However, to insure an adequate sample size, it is advisable to cage or exclose several (10) individuals of the key use species prior to grazing. Measurements of either the remaining leader length or the browsed-tip diameter and basal diameter would be taken for each sample quadrat in which the shrub species had been utilized. This data would then be used in the appropriate regression equation to obtain a predicted or adjusted total production value.

COVER SAMPLING CONCEPTS

Ground cover is defined in the regulations:

> **Ground cover** is the area of ground covered by the combined aerial parts of vegetation and the litter that is produced naturally on site, expressed as a percentage of the total area of measurement (CFR 816.116(d)(3)).

Aerial parts can be interpreted as all aboveground living plant material. Figure 7 depicts the difference between aerial cover or maximum spread of the foliage and basal area. Standing dead material, other than current year's growth, should be included in the litter category as should dead fallen organic material.
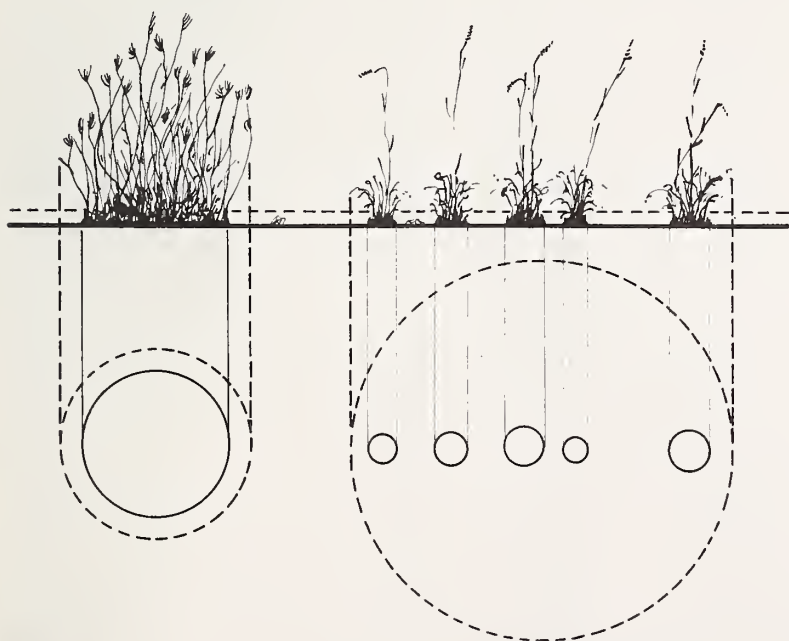

Figure 7.—*Aristida purpurea* (left) and *Bouteloua gracilis* showing the difference between maximum spread of the foliage (aerial cover) and basal area.

Comparison of the cover of a revegetated area to an approved standard will require sampling the revegetated area with the same methods and units of measure that were used to establish the standard. Cover data may be collected by species or life-form, but should be consistent with production and diversity methodology.

In addition to living plant material and litter, bare ground, gravel 0.25 to 3 inches (0.6 to 7.6 cm), and rock >3 inches (7.6 cm) will be recorded. They require little extra effort and provide important site information because they contribute to soil surface protection from raindrop impact and other erosional processes.

Cover is only a valid comparative measure when both the reference and the revegetated areas have received equal levels of utilization or none at all.

COVER SAMPLING METHODOLOGY

Numerous methods are available for estimating vegetation cover (see Pieper 1973). Several studies have shown that the point-quadrat and line-intercept methods are generally the most accurate in estimating the actual cover of herbaceous and shrubby vegetation. They exhibit reasonably low variability between sample quadrats. A relatively recent innovation with a high degree of accuracy involves determining cover from 35mm slides of individual sample quadrats. An accurate and efficient method for estimating basal area of tree stands is Bitterlich's variable radius method. The methodology, specific use, and limitations of these three methods are given here. Determination of the number of samples necessary to achieve statistical adequacy is explained in the section on statistics. Locating samples within the sampling unit should be based upon one of the schemes outlined in the section on random sampling schemes.

Point-Quadrat Method

The point-quadrat method can be used as a nondestructive method for determining aerial and/or basal cover and the layers of vegetation cover within a community. (An example data form is shown in figure 3.) The methods used are as follows:

1. A point or pin frame with multiple pins (10 are frequently used) is randomly located within the sampling units (see fig. 8).
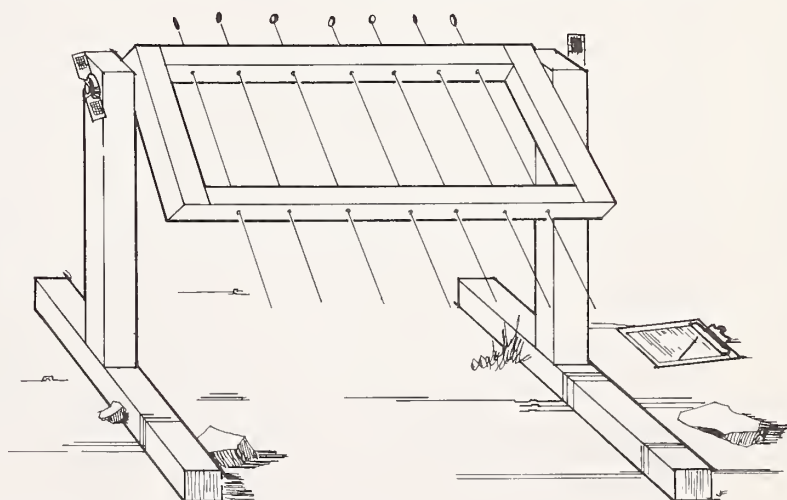

Figure 8.—A point frame device.

2. The individual sharpened pins are lowered down through the vegetation canopy. Each contact with the pinpoint is recorded by species or growth-form (see fig. 9). If a pin hits the same species more than once, only the first contact is recorded.

Basal hits are recorded by species or growth-form or as bare ground, gravel, rock, litter, and moss or lichens. Depending upon the information desired, the investigator may record only the first vegetation contact and/or the basal hit.

Site Name _____

Date _____ Location _____

_____

Sample size _____ Investigators _____

SEC _____
TWP _____
RNG _____

GROUND COVER DATA

BASAL	CATEGORY	DOT	COUNT	NO.
B	Bare Ground			
P	Persistent Litter			
N	Non-Persistent Litter			
G	Gravel (2mm–3")			
R	Rock (>3")			

Record ground cover category and/or species symbol of each successive hit. Single hits on ground cover need only be recorded above.

BASAL	CANOPY 1	CANOPY 2	CANOPY 3	DOT COUNT NO.	BASAL	CANOPY 1	CANOPY 2	CANOPY 3	DOT COUNT NO.

TOTAL NUMBER POINTS   TOTAL NUMBER POINTS

Work Area/Remarks

Figure 9.—Data form for the point quadrat method.

3. The sample size required to obtain statistical adequacy is usually 100 to 300 pins. A method for determining the exact sample size is given in the section on statistics.

4. The data are summarized either by frame (the 10 pins) or by transect for statistical analysis.

5. Several cover values can be derived from this information:

a. Percent aerial cover for each species or life-form equals the sum of all first hits on that species or life-form divided by the sum of all first hits on vegetation, plus first hits on bare ground, gravel, rock, litter, and moss or lichens.

b. Percent total aerial cover equals the sum of all first hits on vegetation divided by the sum of all first hits on vegetation plus all first hits on bare ground, gravel, rock, litter, and moss or lichens. Values for the individual components of basal cover (vegetation, bare ground, rock, gravel, litter, and moss or lichens) can be calculated in a similar manner.

c. The percent vegetation cover by species equals the total number of canopy hits by species or life-form divided by the total number of canopy hits.

Additional considerations for point-quadrat sampling are:

1. The frame should be held vertically for measuring cover. Frames placed at an angle may result in an increase in the number of interceptions and in an overestimate.

2. The dimensions of the frame should accommodate the height and spacing of the plants to be sampled. A typical frame is 3 ft (0.9 m) high and 3 ft (0.9 m) long with wire pins or steel rods placed 4 inches (10 cm) apart and the same length as the legs. It should have two guide bars to slide the pins through to minimize sample bias.

3. The pin or rod must be sharp, as dull or blunt pins may result in an overestimate.

4. This method cannot be used when vegetation is moving in the wind.

5. The frame should be built so that the pinpoint does not vibrate when the pins are moved.

This method is best suited for sampling normally sized 8 to 20 inches (20 to 50 cm) tall, herbaceous or dwarf shrub vegetation. It should not be used in shrubby vegetation.

Line-Intercept Method

The line-intercept method can be used to measure aerial cover of plants with fairly solid crown cover (almost 100 percent) or relatively large basal areas. It is best suited for measuring aerial cover of woody plants, shrubs, and trees. (A suggested data form is presented in figure 10.) The methodology is as follows:

1. A line of predetermined length, preferably a tape measure, is stretched tightly across the vegetation. The line should be objectively located. The best sampling procedure is the stratified-random sample using a base line and perpendicular transects.

Site Name _____ Data Sheet No. ____ of ____ SEC _____

Date _____ Location _____ TWP _____

Line Length _____ Investigators _____ RNG _____
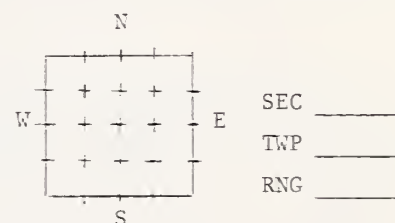
| Species | Line Number | | | | | Total |
	1	2	3	4	5	

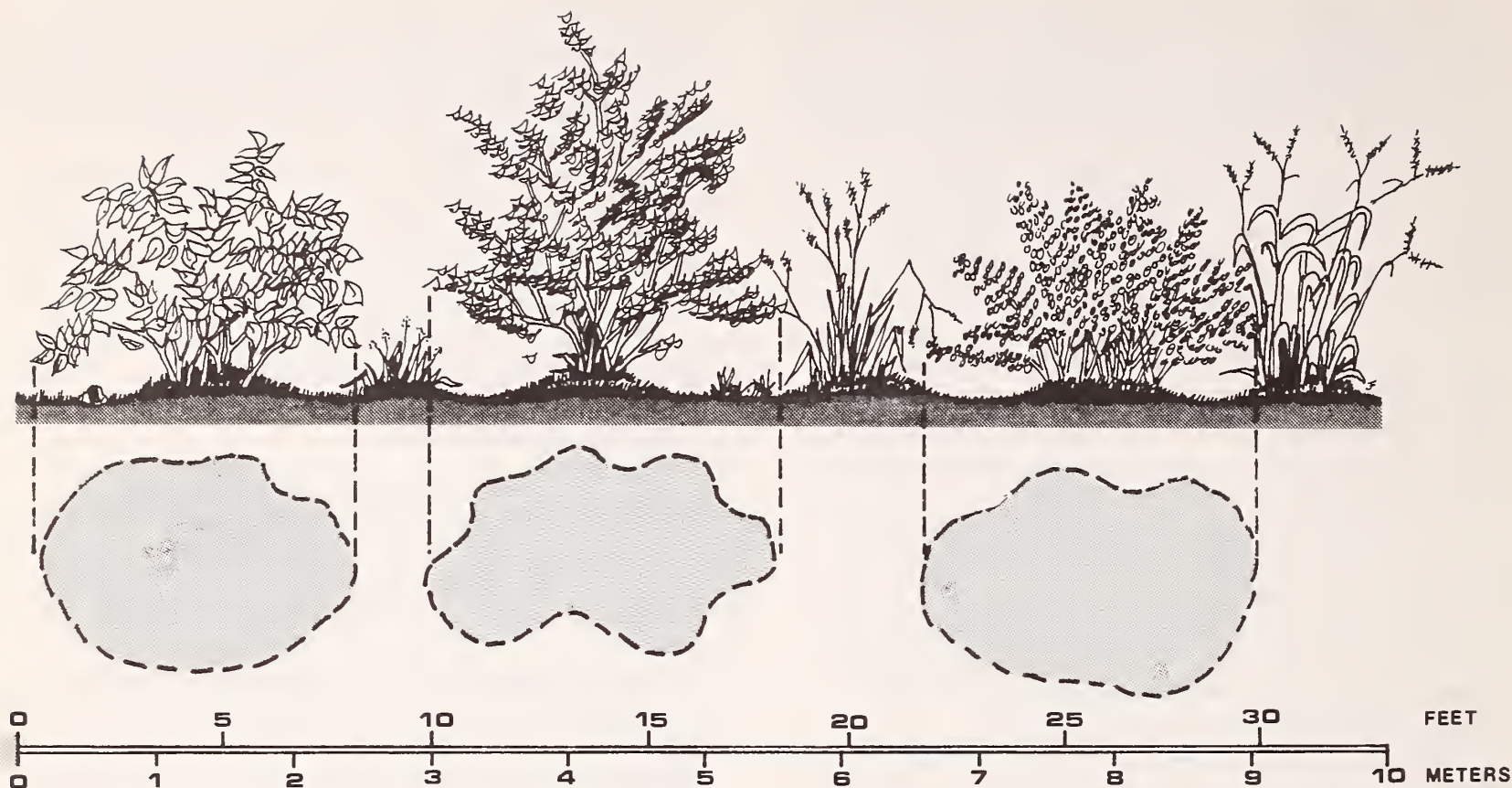Figure 10.—Data form for the line intercept method.

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Figure 11.—Use of the line intercept method.

2. The canopy intercept of each species along the line is measured from the tape or with a rule. This procedure is shown in figure 11. If the canopies overlap in layered vegetation, it may be desirable to measure each height layer separately.

3. Transect lines should be between 35 and 350 ft (10 m and 100 m) in length. Many short lines are generally preferred to a few long lines. A minimum of about 5 to 10 transects are usually required for an adequate sample. (Determinination of an exact sample size is explained under the section on statistics).

4. Data are summarized by transect line for statistical analysis.

5. Percent cover is calculated for each transect by species. The length intercepted by a species is divided by the transect length and multiplied by 100. The percent cover of a species by sampling unit is determined by dividing the sum of the individual transect lengths intercepted by the total transect length sampled then multiplying by 100.

Special considerations for this method are:

1. The line-intercept method should only be used for vegetation with well-defined canopies. In mixed communities of grasses and shrubs, it may be desirable to use the point-quadrat method for herbaceous vegetation and the line-intercept method for shrubs. The point-quadrat frames could be randomly located along the transect line used to measure shrub cover.

2. Data must be clearly recorded so that each shrub interception can be separated. It may be desirable to add additional lines for recording values to the line-intercept data form.

3. If the canopies of individual plants are not always solid, their interception along the tape should be consistently interpreted. For example, when a shrub has bushy branches that reach across the tape with gaps in between, the gaps should not be measured. Small within-plant gaps are best ignored.

35mm Slide Method

The 35mm slide method is an accurate means of determining the aerial cover of vegetation. Individual sample quadrats are first photographed in the field. Later, the percent of the quadrat covered is determined from a grid onto which the developed slide is projected. The methods used are as follows:

1. Sample quadrats are randomly located in the sample area using any one of the random sampling schemes previously described. The same quadrats used to photograph cover can be used to sample production, but cover must be photographed before production is sampled.

2. The quadrat is labeled according to the location, date, and quadrat number. Labeling can be accomplished with individual cards for each quadrat, or a film imprinting system such as the Recordata Back available for Olympus cameras can be used.

3. A tripod and camera bar are used to position the camera vertically over the center of the quadrat. A camera bar can be constructed that mounts on the tripod perpendicular to the ground. On one end of the bar a screw-mount for attaching the camera can be positioned. On the other end of the bar a counter-weight equivalent to the weight of the camera can be affixed.

The size of the camera lens used should be determined by the size of the quadrat. When viewed through the lens, the quadrat should encompass the majority of the area outlined in the lens without distortion.

4. The focus, lens aperture, and shutter speed is adjusted for each quadrat and the photograph is taken.

Analysis of the processed film proceeds as follows:

5. The slide is projected onto a grid with 100 squares. The vertical and horizontal axes of the grid must have the same

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proportionate lengths as the vertical and horizontal axes of the quadrat frame. The slide projector is adjusted so that the area within the quadrat exactly matches that within the grid.

6. The number of grid squares covered by vegetation, litter, bareground rock, and gravel are counted. The number of squares counted is equivalent to the percent of each cover category within the sample grid.

In sparse communities where individual plants can be identified from the slide, it may be possible to obtain percent cover by species.

7. Data are summarized by quadrat for statistical analysis. Percent cover values can be derived for each of the cover categories (total vegetation litter, bareground rock, and gravel). In some cases percent cover can also be determined for life forms and or species.

Other considerations for the use of this method are:

1. The 35mm slide method is not well suited to sampling schemes that involve large quadrat sizes. Quadrats larger than about 0.5 m² cannot easily fit within the area encompassed by standard lens sizes.

2. This method is not well-suited to tall vegetation (over 1 m). In mixed communities of grasses and shrubs the 35mm slide method can be used to assess grass and forb cover, and the line-intercept method can be used to evaluate shrub cover.

Bitterlich's Variable Radius Method

The Bitterlich method is an efficient means of obtaining basal area and density of tree species. It is a plotless method of selecting sample trees on the basis of size rather than frequency of occurrence. (See Hovind and Rieck 1970; Mueller-Dombois and Ellenburg 1974; Dilworth 1964; and Avery 1967.) A point sample is used and trees are selected for tallying with the use of an optical wedge, prism, or angle gage. The probability of tallying any given tree is proportional to its stem basal area (BA). Trees may be thought of as being encircled by imaginary zones proportional to stem diameter. These zones determine which trees are tallied (see fig. 12). The sighting angle used is based upon the average size and distribution of the trees in the stand. Each sighting angle has a corresponding basal area conversion factor (BAF), which allows the calculation of basal area and density. Table 5 lists the common basal area factors and angle sizes used in point sampling. An example data form is presented in figure 13. The methods used are as follows:

1. Trees are tallied in a complete circle around the investigator using an optical wedge, prism, or angle gage of a preselected basal area factor (BAF) by 2-inch (5-cm) diameter class. Optical wedges or prisms are held directly over the sampling point. If an angle gage is used, the crosspiece is held over
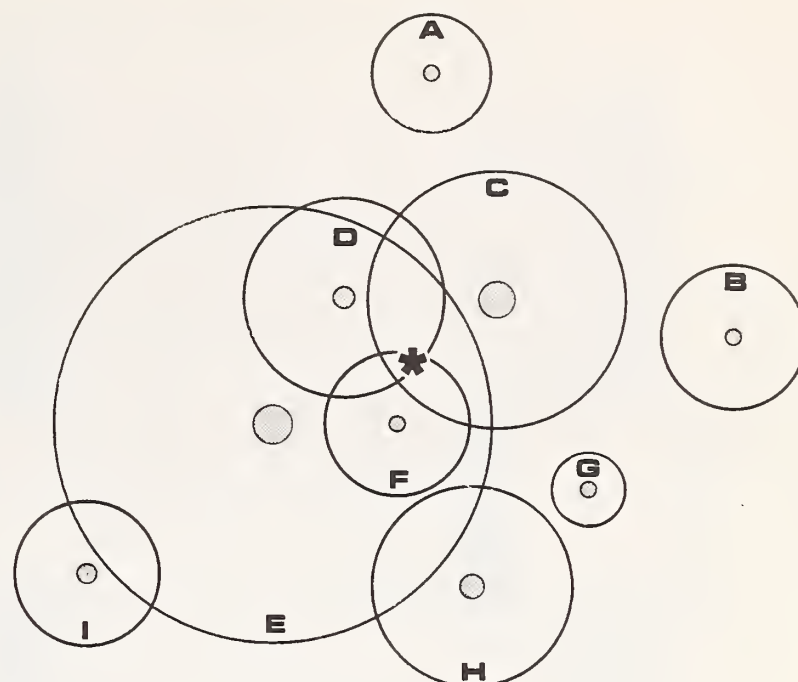
Figure 12.—Imaginary zones proportional to stem diameter and encircling each tree determine which trees will be tallied at a given point (from Hovind and Rieck 1970).

Table 5.—Common basal area factors and angle sizes used in point sampling

Basal area factor	Angle size, min	Angle size, diopters	Ratio (tree diameter to plot radius)	Plot radius factor
1	32.94	0.96	1/104.4	8.696
2	46.59	1.36	1/73.8	6.149
3	57.06	1.66	1/60.2	5.021
4	65.89	1.92	1/52.2	4.348
5	73.66	2.14	1/46.7	3.889
10	104.18	3.03	1/33.0	2.750
15	127.59	3.71	1/26.9	2.245
20	147.34	4.29	1/23.3	1.944
25	164.73	4.79	1/20.9	1.739
30	180.46	5.25	1/19.0	1.588
35	194.92	5.67	1/17.6	1.470
40	208.38	6.07	1/16.5	1.375
50	232.99	6.79	1/14.8	1.230
60	255.23	7.44	1/13.5	1.123

From Hovind and Rieck 1970.

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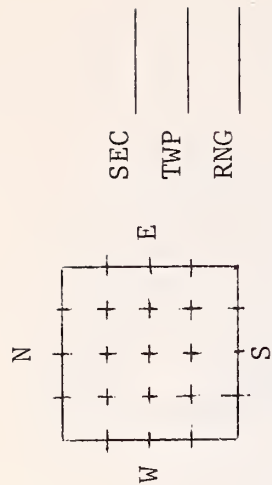
Site Name _____

Location _____

Date _____

Basal Area Factor _____

Investigators _____

Data Sheet No. _____ of _____

SEC _____
TWP _____
RNG _____

N
E
S
W

Two-Inch Dia. Class	Point Number																Mean Tally	BA Per Acre*	BA Per Tree	Trees Per Acre
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16				
2																			0.022	
4																			0.087	
6																			0.196	
8																			0.349	
10																			0.545	
12																			0.785	
14																			1.069	
16																			1.396	
18																			1.767	
20																			2.182	
22																			2.640	
24																			3.142	
26																			3.687	
28																			4.276	
30																			4.909	
32																			5.585	
34																			6.305	
36																			7.069	
Totals																				

*square feet

REMARKS: _____

Figure 13.—Data form for the Bitterlich variable radius method.

NO TALLY   ▨ TALLY   BORDERLINE
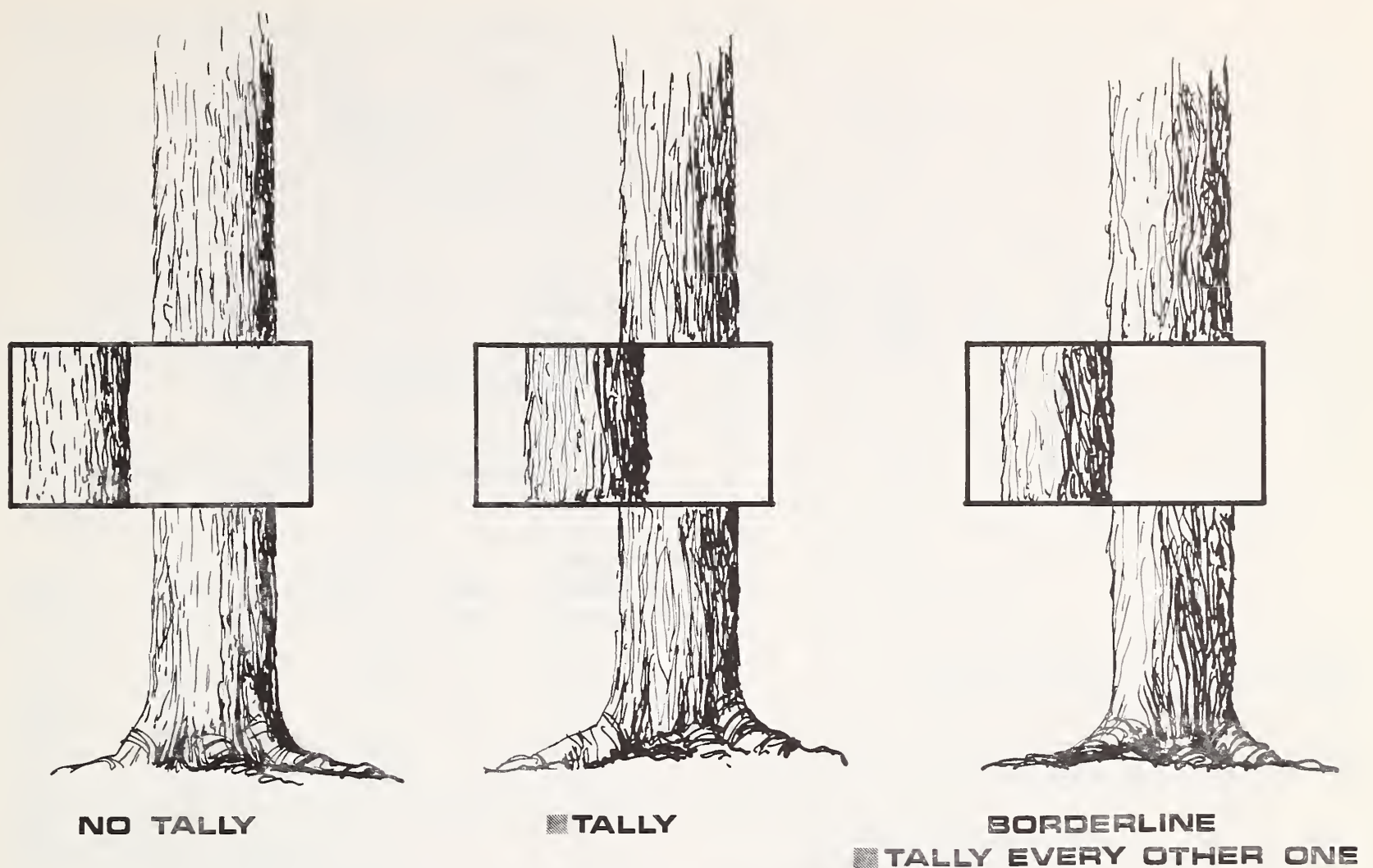   ▨ TALLY EVERY OTHER ONE

Figure 14.—Use of the optical wedge or prism for point sampling (from Avery 1967).

the point. When using the wedge or prism, a tree is counted when its stem is not completely offset when viewed through the wedge. All other trees are ignored (see fig. 14). If a stick-type angle gage is used, all trees larger than the defined angle (crosspiece) are counted and those that are smaller are ignored. In both cases, borderline trees should be tallied as a half tree.

Trees should be tallied by species. All trees should be sighted at breast height. The same tree may be tallied from two different sample points; however, points should be spaced widely enough so this occurs infrequently.

2. In sloping terrain, compensation must be made for the effect slope has in decreasing the sighting angle. There is no method available for correcting for slope with the stick-type angle gage. An abney or clinometer can be used in correcting for slope when using the optical wedge or prism. If an abney is used, the slope angle is measured and "locked in." The abney is then held level, the prism or optical wedge is placed on the sloping angle of the abney, and trees are tallied while viewing the prism or wedge held on the sloping angle. When a clinometer is used, the slope is determined and the clinometer is held at the angle of the slope. The prism or optical wedge is placed on the sloping angle of the clinometer, and trees are tallied from this angle. Each tree to be tallied requires a new measurement of slope.

An instrument that can be used instead of the wedge, prism, or angle gage and that automatically corrects each angle for slope is the Spiegal relascope. Sighting angles are provided for basal area factors of 5, 10, 20, or 40. The convenience of the

Spiegal relascope may be outweighed by its expense, however, and it does not have the optical qualities for good visibility on dark and rainy days.

3. The number of trees tallied will be dependent upon the BAF and its corresponding sighting angle. The average size and distribution of the trees in the sample unit determine the selection of a BAF. A sampling unit with numerous small trees should be sampled with a narrow sighting angle (small BAF). A narrow sighting angle extends a greater distance to include trees of smaller diameter (see fig. 15). In stands with large tree diameters, the angle is increased (large BAF) to prevent extremely large tallies. The BAF is normally selected so that 5 to 12 trees will be tallied at each sample point.

The BAF is determined for stick-type angle gages by the width of the crosspiece and the length of the angle gage (stick). Table 6 gives the relationships between the width of the crosspiece and the length of the angle gage. It is possible for the investigator to construct angle gages for a specified BAF using these relationships. Such gages should be calibrated for each sampler. (The calibration technique is described in a later section.)

4. For statistical analysis, the data should be summarized by sample point regardless of diameter class.

5. The computations for determining mean tally, basal area (BA) per acre, and the number of trees per acre for each 2-inch diameter class are:

$$\text{Mean tally} = \frac{\text{No. of trees tallied per diameter class}}{\text{Total no. of sample points}}$$
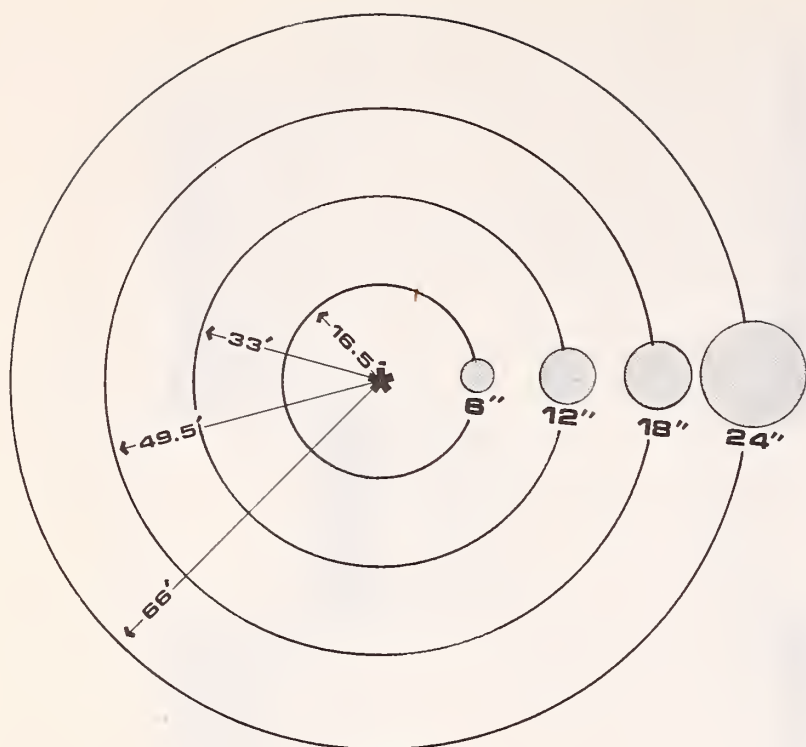
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Figure 15.—Ratio of tree diameter to plot radius for BAF 10 (from Hovind and Rieck 1970).

Table 6.—*Relationships between crossarm and length of angle gage*

| Width of crossarm | Length of angle-gage | | |
	BAF 5	BAF 10	BAF 20
	---------- Inches ----------		
0.25	11.67	8.25	5.83
.30	14.00	9.90	7.00
.35	16.33	11.55	8.17
.40	18.67	13.20	9.33
.45	21.00	14.85	10.50
.50	23.34	16.50	11.67
.55	25.67	18.15	12.83
.60	28.00	19.80	14.00
.65	30.34	21.45	15.16
.70	32.67	23.10	16.33
.75	35.00	24.75	17.50
.80	37.34	26.40	18.66
.85	39.67	28.05	19.83
.90	42.00	29.70	21.00
.95	44.34	31.35	22.16
1.00	46.67	33.00	23.33

BAF 5 has a ratio of 1/46.67; therefore length of stick is 4.667 inches per 0.1 inch of crossarm.

BAF 10 and 20 have ratios of 1/33 and 1/23.33; therefore length of stick is 3.300 inches and 2.333 inches per 0.1 inch of crossarm respectively.

From Hovind and Rieck 1970.

Basal area per acre = No. of trees tallied × BAF

$$\text{No. of trees per acre} = \frac{\text{Basal area per acre}}{\text{Basal area per tree}}$$

Total BA per acre, total number of trees per acre, and mean tree size per acre are calculated as follows:

Total basal area per acre = Total no. trees tallied × BAF

Total no. trees per acre = Sum of no. of trees per acre in each diameter class

$$\text{Mean tree size per acre} = \frac{\text{Total basal area per acre}}{\text{Total no. trees per acre}}$$

An example of the summary data calculations is given in table 7 and related information is found in table 8.

Table 7.—*Example of summary data calculations for the Bitterlich's variable radius method. Basal area factor equals 25*

Two-inch diameter class	Mean tally	Basal area per acre	Basal area per tree*	Trees per acre
6	1	25	0.196	127
8	2	50	.349	143
10	3	75	.545	138
12	1	25	.785	32
Total	7	175		440

Basal area per acre = (No. tallied trees) × BAF = 7 × 25 = 175 ft²/acre

$$\text{Total trees per acre} = \frac{\text{basal area/acre}}{\text{basal area/tree}} = \frac{25}{0.196} = 127$$

$$\text{Mean tree size per acre} = \frac{175}{440} = 0.3977 \text{ ft}^2 \text{ basal area}$$

$$= 8.5 \text{ inches diameter}$$

*From table 8

Additional information concerning this method is given below:

1. Angle gages, prisms, and optical wedges are readily available from most scientific supply houses, such as Ben Meadows Forestry, Engineering and Educational Supples, 3589 Broad St., Atlanta (Chamblec), GA 50366; and Forestry Suppliers, Inc., 205 West Rankin St., Box 8397, Jackson, MS 39204. (These addresses are provided solely for information and not for advertising purposes.)

2. If angle gages, prisms, or optical wedges of unknown quality are obtained and the exact BAF is unknown, the instrument must be calibrated. Because sighting habits of individual samplers vary, it is often desirable to calibrate all instruments regardless of price or supposed precision. Calibration is accomplished by placing a circular target of known diameter such as

Table 8.—*Derivation of the basal area factor of 10 ft² per acre for point sampling*

Tree dbh. (1)	Imaginary plot radius, (2)	Imaginary plot size (3)	Trees per acre,* No. of stems (4)	Basal area per tree (5)	Basal area per acre, (6)
Inches	Feet	Acres		---------- Ft² ----------	
4	11.00	0.0087	114.94	0.087	10
6	16.50	.0196	54.02	.196	10
8	22.00	.0349	28.65	.349	10
10	27.50	.0545	18.35	.545	10
12	33.00	.0785	12.74	.785	10
14	38.50	.1069	9.35	1.069	10
16	44.00	.1396	7.16	1.396	10
18	49.50	.1767	5.66	1.767	10
20	55.00	.2182	4.58	2.182	10
22	60.50	.2640	3.79	2.640	10
24	66.00	.3142	3.18	3.142	10
26	71.50	.3687	2.71	3.687	10
28	77.00	.4276	2.34	4.276	10
30	82.50	.4909	2.04	4.909	10
32	88.00	.5585	1.79	5.585	10
34	93.50	.6305	1.59	6.305	10
36	99.00	.7069	1.41	7.069	10
Method of calculation	dbh × 2.75	$\dfrac{\pi r^2}{43,560}$	$\dfrac{1.00}{\text{plot size}}$	0.005454D²	column 4 × 5

*Exact value for number of trees per acre may vary slightly, depending upon number of decimal places expressed for imaginary plot size.
From Hovind and Rieck 1970.

1 ft (0.3 m) against a contrasting background. The sampler backs away from the target until the prism or optical wedge image is displaced as shown for the "borderline" tree in figure 14, or until the target exactly fills the sighting angle of the stick-type angle gage. The exact distance to the target from the crosspiece of the angle gage, or from the sampler's eye in the case of prisms or optical wedges, is then measured. The BAF is calculated using the following formula:

$$BAF = 10,890 \frac{W^2}{D}$$

W is the diameter (width) of the circular target in feet, and D is the distance to the target in feet. This calculated BAF is then used in all subsequent computations.

STOCKING RATE (DENSITY) SAMPLING

The Federal regulations state that areas revegetated with trees or shrubs will have a minimum stocking rate of 450 trees or shrubs per acre (1 125/ha). Areas developed for fish and wildlife management and permit areas of 40 acres (16 ha) or less have slightly different requirements. Refer to the regulations from the Federal Register in appendix I for the specific requirements for these situations.

Density, or stocking rate, means the number of individual trees or shrubs per unit area. Several sampling methods are available for estimating the density of trees and shrubs. Methods that are accurate and applicable to sampling revegetated areas are the Bitterlich variable radius method for trees and the density quadrat method for shrubs.

Bitterlich's Variable Radius Method for Trees

The Bitterlich's variable radius method is a reliable technique for estimating tree density. The procedures for this method were given under the section on cover methodology and should be used to obtain tree density or stocking rate.

Density Quadrat Method for Shrubs and Trees

Samples should be located within the sampling unit by using one of the schemes outlined in the section on random sampling schemes. An example data form is presented in figure 16. The specific methodology is as follows:

1. The sample quadrat is randomly placed within the sampling unit. Square and rectangular quadrats can be established with the use of tape measures. The quadrat should be oriented in a consistent direction from the initial sampling point for all samples taken. Circular quadrats can be established surrounding the sampling point by positioning one end of a rope of fixed radius over the sampling point and rotating the other end of the rope around the point in a complete circle. All shrubs or trees within the quadrat are counted while the rope is being rotated.

2. All shrubs or trees within the quadrat are counted and recorded by species (see fig. 16). Shrubs or trees rooted within the quadrat are counted; those rooted outside of the quadrat are not included in the sample.

3. Individual quadrat values summarized by species are used for statistical analysis.

	Site Name _____									Data Sheet No. ____ of ____										SEC _____
	Date _____ Location _____									W ... E										TWP _____
	Quadrat size _____ Investigators _____																				RNG _____

	Quadrat Number																				
Species	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sheet Total

REMARKS: _____

Figure 16.—Data form for the density quadrat method.

4. A method for determining sample size is given in the section on statistics. The probability level used should be 0.10.

Additional considerations for this method are as follows:

1. **Quadrat size** should be based upon the size and the spacing of the individual shrubs or trees. A quadrat size containing an average of four individuals is often recommended; however, any number of individuals can be contained within the quadrat if accurate counts can be made. Square quadrats of 13.2 × 13.2 ft (4 × 4 m) are commonly used for shrub species up to 9.9 ft (3 m) height. Circular quadrats with radius of 11.7 ft (1/100 acre) (3.566 m [0.004 ha]) or 8.3 ft (1/200 acre) (2.529 m [0.002 ha]) are also frequently used for shrubs. For trees, circular quadrats with radius of 16.7 ft (1/50 acre) (5.09 m [0.008 ha]) are often used.

2. **Quadrat shape** has little effect on the accuracy of density measurements in uniformly distributed vegetation. Rectangular quadrats are considered more accurate than other quadrat shapes in patterned vegetation when the long axis of the rectangular quadrat transects any banding in the vegetation pattern. Circular quadrats are probably the most efficient quadrat shape for field implementation.

3. The most efficient and reliable method of evaluating small or irregularly shaped plantings may be a direct count of all living and dead shrubs or trees. A determination of survival rate (the number of living trees or shrubs divided by the total number of trees or shrubs planted) will be sufficient for determining adequacy of revegetation. The minimum acceptable survival rate will be dependent upon the planting scheme and the management plan for the area, but should never be less than 80 percent. This method is particularly well suited to shrubs or trees that are planted in strips or rows as hedgerows or windbreaks.

DIVERSITY CONCEPTS

The concept of diversity has received numerous interpretations in the scientific literature. During recent years, however, there has been a consensus that diversity has two basic components. The first, species richness, pertains simply to the number of species within a defined area. The second, species evenness, refers to the proportionate distribution of individuals among species. These two components of diversity are often assessed together and called "heterogeneity."

Ideally, a comparison of the diversity of two areas would determine if the areas had similar species numbers and if the distribution of individuals among species was approximately the same. It should follow then that the measurement of diversity requires a list of the species in the area under investigation and a measure of each species importance or the contribution of the sum of its individuals to the community. Measures of importance are derived from estimates of numbers (density), production, or cover. (The selection of the appropriate importance measure is discussed in a following section.)

Although diversity is usually discussed in terms of species, it may also be thought of in terms of life-forms. Indeed, the use of life-forms in the comparison of the diversity of a reference area and a revegetated area may be more appropriate, especially if species different from those in the reference area are seeded in the revegetated area.

Many excellent references on the concepts of diversity are available to the interested reader. They include Mueller-Dombois and Ellenberg (1974), Peet (1974), Pielou (1975, 1974, and 1966), and Whittaker (1972 and 1965).

Several methods of comparing the diversity of two areas are available to the investigator. These can, in general, be categorized as diversity indices, rank correlation tests, and similarity

indices. Similarity indices probably provide the best available method for comparing reference and revegetated areas. However, presented here is a specific example of each category chosen on the basis of its appropriateness for the comparison of reference and revegetated areas. These include Shannon's diversity index, H′, Spearman's rank correlation coefficient, R_o, and Sorenson's similarity index. The basic concepts, assumptions, and limitations of each are discussed and the necessary calculations are illustrated. Table 9 shows the requirements and comparisons of all three.

Shannon's Diversity Index—H′

Indices of diversity are, perhaps, the most frequently used measure of diversity. They are often assumed to provide "absolute" measures of diversity regardless of the type of importance value or the kind of communities being investigated. However, there are certain assumptions and constraints associated with diversity indices that must be considered.

1. In general, diversity indices assume that all individuals are equal to one another. This is obviously not the case with such diverse life-forms as trees and grasses or forbs and shrubs. In addition, the desirability of a species, for example a perennial native grass versus an annual introduced forb, is not taken into account.

2. There is no mathematical way to compare values obtained from two different communities using the same diversity index. This is because a change in the index at one end of the scale is not necessarily proportionate to the same amount of change at the other end.

3. When examining two different communities, diversity indices do not always reveal changes in the apportionment of individuals among species. For example, a reference area might have species A, B, C, D, and the apportionment of individuals might be 10, 2, 2, 1, respectively. If the revegetated area had the same species, A, B, C, D, but the apportionment of individuals were reversed, 1, 2, 2, 10, the diversity indices would still be the same for both areas.

4. The timing of sampling can have a large influence on diversity indices. This is primarily due to the contribution or lack

of annual species that may exhibit ephemeral characteristics.

Although diversity indices have received widespread use, their applicability in the comparison of revegetated areas to reference areas is questionable, and it is recommended that they not be used. However, because of the current popularity of diversity indices, a discussion and example of the Shannon H′ diversity index is presented.

The Shannon index, one of the most widely used diversity indices, measures heterogeneity (richness and evenness). It is based upon the assumption that the more species there are and the more even the distribution of individuals among species, the greater the diversity (Pielou 1966). The formula for an infinite population is:

$$H' = -\sum_{i=1}^{s} p_i \log p_i$$

where p_i is the percentage importance. The index, H′, is logarithmically related to the number of species. It is most sensitive to changes in the importance of the rare species in the sample (Peet 1974). For samples containing only a few species, this index may result in low dispersion and may be influenced by the quantitative relation of the dominant species. Like most indices of this type, the importance value used (density, cover, or production) will affect the value of H′.

The base of the logarithm used is immaterial. Changes in the base of the logarithms only change the units in which diversity is measured (Pielou 1974). It is necessary, however, to state the units that are used.

An example calculation for the Shannon index using logarithms of base 10 is given in table 10. The importance value used is dry weight (DW) production and the percentage of the importance value, p_i, is the percent production of each species or life-form of the total production. Because the maximum value of H′ is equal to one, the H′ values obtained here, 0.872 for the revegetated area and 0.969 for the reference area, are actually very high. If it can be assumed that the calculated H′ value accurately depicts the diversity of the reference area, then the H′ value of the revegetated area would have to be within a

Table 9.—A comparison of Shannon's index, Spearman's R_o, and Sorenson's similarity index

Characteristics	Shannon's index H′	Spearman's R_o	Sorenson's similarity index
Requires species or life form list	X	X	X
Requires measure of importance; production, cover, or density	X	X	X
Requires same number of species or life forms in both areas		X	
Does not require same number of species or life forms in both areas	X		X
Tests apportionment of species or life forms between areas		X	X
Does not test apportionment of species or life forms between areas	X		
Independent diversity index for each area	X		
Diversity measure derived from comparison of both areas		X	X

Table 10.—*An example calculation of the Shannon index*

Life form or species	Revegetated area			Reference area		
	lb/acre DW	p_i	$-(p_i \log p_i)$	lb/acre DW	p_i	$-(p_i \log p_i)$
1	553	0.200	0.140	524	0.177	0.133
2	479	.173	.132	348	.117	.109
3	234	.084	.090	441	.149	.123
4	625	.226	.146	563	.190	.137
5	351	.127	.114	197	.066	.078
6	26	.009	.018	151	.051	.066
7	108	.039	.055	94	.032	.048
8	84	.030	.046	175	.059	.073
9	67	.025	.039			
10	242	.087	.092			
11				269	.091	.095
12				43	.014	.026
13				123	.042	.058
14				36	.012	.023
Σ	2,769	1.000	.872	2,964	1.000	.969

certain limit of the reference area H′ in order to meet the diversity criteria. In interpreting and in calculating diversity indices, however, the following considerations must be made:

1. H′ is a relative value. The H′ for the reference area is not directly comparable to H′ for the revegetated area, nor are the individual values of $-(p_i \log p_i)$.

2. Since H′ is a relative value, the individual values of $-(p_i \log p_i)$ are not proportionate to one another and cannot be reapportioned to equal 100 percent.

3. All species or life-forms must be included in the percentage importance value. Eliminating certain species will disproportionately weight the importance of other species.

If the Shannon index is to be used in the evaluation of the diversity of reference and revegetated areas, it is important that the undesirable or weedy species not be used as a basis for comparison. They should be included in the total community value (density, cover, or production) from which the individual species importance values (a percentage of the whole) are derived, but the more desirable species in the community should be used to determine if the diversity criteria have been met.

Spearman's Rank Order Correlation Coefficient—R_o

A direct, statistical comparison between the importance values (production, cover, or density) of the species of reference and revegetated areas appears to be a logical method for assessing diversity. Spearman's R_o is a nonparametric statistical test that provides a comparison of the apportionment of the species within the two areas. The comparison is based on the difference between the magnitude of importance (ranking) of each of the species that exist in the two areas. Spearman's

rank order correlation coefficient is explained in most statistical texts, such as Sokal and Rohlf (1969), and Snedecor and Cochran (1967).

The constraints of using this test are as follows:

1. Both the reference area and the revegetated area must have the same number of species or life-forms. This test is therefore most applicable for use with life-forms.

2. The use of this test requires the assumption that all rankings are equally likely, or that the distribution of individuals among species rank order applications is perfectly even. Jumars (1980) has stated that this assumption is unreasonable for most natural communities, and may invalidate the use of rank correlation tests for the comparison of similarity among species rank orders of abundance between communities.

The test statistic for Spearman's R_o, Spearman's R_s, is defined by the expression

$$R_s = 1 - \frac{6\Sigma d_i^2}{n(n^2 - 1)}$$

where

d_i = The difference between the two ranks

n = The number of comparisons

The null hypothesis to be tested is that the importance values for the two areas are apportioned between the species or life-forms in the same manner. For a one-sided test of the null hypothesis:

$R_s \leq R_o$: accept H_o

$R_s > R_o$: reject H_o

The critical values of Spearman's rank correlation coefficient, the R_o values, are found in table 11.

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Table 11.—*Critical values of Spearman's rank correlation coefficient*

n	$\alpha = 0.10$	$\alpha = 0.05$	$\alpha = 0.02$	$\alpha = 0.01$
5	0.900	--	--	--
6	.829	0.886	0.943	--
7	.714	.786	.893	--
8	.643	.738	.833	0.881
9	.600	.683	.783	.833
10	.564	.648	.745	.794
11	.523	.623	.736	.818
12	.497	.591	.703	.780
13	.475	.566	.673	.745
14	.457	.545	.646	.716
15	.441	.525	.623	.689
16	.425	.507	.601	.666
17	.412	.490	.582	.645
18	.399	.476	.564	.625
19	.388	.462	.549	.608
20	.377	.450	.534	.591
21	.368	.438	.521	.576
22	.359	.428	.508	.562
23	.351	.418	.496	.549
24	.343	.409	.485	.537
25	.336	.400	.475	.526
26	.329	.392	.465	.515
27	.323	.385	.456	.505
28	.317	.377	.448	.496
29	.311	.370	.440	.487
30	.305	.364	.432	.478

From Olds 1938.

In addition, a t^* value can be calculated to test the null hypothesis:

$$t = R_s \sqrt{(n-2)/(1-R^2_s)} \cdot$$

The calculated t value is compared with t_{n-2} ($\alpha/2$) from the t-table (refer to table 12).

$t^* \leq t_{n-2}$ ($\alpha/2$): accept H_o

$t^* > t_{n-2}$ ($\alpha/2$): reject H_o

An example of a comparison between a revegetated area and a reference area using Spearman's R_o is given in table 13. The species or life-form from each area is first ranked according to the magnitude of the importance value. The difference between the two ranks of those species or life-forms found in both areas, d_i, is then obtained by subtracting rank 1, R_1, from rank 2, R_2. The value of d_i^2 is derived by squaring each of the values of d_i. Once these values have been obtained, the test statistic for Spearman's R_o or R_s is computed:

$$R_s = 1 - \frac{6\Sigma d_i^2}{n(n^2-1)}$$

$$= 1 - \frac{6(56)}{12(12^2-1)}$$

$$= 1 - \frac{336}{1716}$$

$$= 0.804$$

The R_o value for n = 12 and = 0.10 is 0.497 (see table 11). Because the test statistic, $R_s = 0.804$, is greater than the critical value, $R_o = 0.497$, the null hypothesis is rejected. The revegetated area presented in this example did not meet the criteria established for successful revegetation, because the species importance values for the two areas were not apportioned in a similar manner.

If t values are tested, the analysis is

$$t^* = \sqrt{(12-2)/(1-.804^2)}$$

$$= 4.276$$

Because the value for t_{10} (0.05), 1.812, is less than the calculated t^* value, 4.276, the null hypothesis is rejected.

Table 12.— *t-Distribution values for various levels of n, or degrees of freedom, d.f., for a one-sided test*

	Probability of a larger value of t, sign considered								
df	0.25	0.2	0.15	0.1	0.05	0.25	0.01	0.005	0.0005
1	1.000	1.376	1.963	3.078	6.314	12.706	31.821	63.657	636.619
2	.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	31.598
3	.765	.978	1.250	1.638	2.353	3.182	4.541	5.841	12.941
4	.741	.941	1.190	1.533	2.132	2.776	3.747	4.604	8.610
5	.727	.920	1.156	1.476	2.015	2.571	3.365	4.032	6.859
7	.711	.896	1.119	1.415	1.895	2.365	2.998	3.449	5.405
8	.706	.889	1.108	1.397	1.860	2.306	2.896	3.355	5.041
9	.703	.883	1.100	1.383	1.833	2.262	2.821	3.250	4.781
10	.700	.879	1.093	1.372	1.812	2.228	2.764	3.169	4.587
11	.697	.876	1.088	1.363	1.796	2.201	2.718	3.106	4.437
12	.695	.873	1.083	1.356	1.782	2.179	2.681	3.055	4.318
13	.694	.870	1.079	1.350	1.771	2.160	2.650	3.012	4.221
14	.692	.868	1.076	1.345	1.761	2.145	2.624	2.977	4.140
15	.691	.866	1.074	1.341	1.753	2.131	2.602	2.947	4.073
16	.690	.865	1.071	1.337	1.746	2.120	2.583	2.921	4.015
17	.689	.863	1.069	1.333	1.740	2.110	2.567	2.898	3.965
18	.688	.862	1.067	1.330	1.734	2.101	2.552	2.878	3.922
19	.688	.861	1.066	1.328	1.729	2.093	2.539	2.861	3.883
20	.687	.860	1.064	1.325	1.725	2.086	2.528	2.845	3.850
21	.686	.859	1.063	1.323	1.721	2.080	2.518	2.831	3.819
22	.686	.858	1.061	1.321	1.717	2.074	2.508	2.819	3.792
23	.685	.858	1.060	1.319	1.714	2.069	2.500	2.807	3.767
24	.685	.857	1.059	1.318	1.711	2.064	2.492	2.797	3.745
25	.684	.856	1.058	1.316	1.708	2.060	2.485	2.787	3.725
26	.684	.856	1.058	1.315	1.706	2.056	2.479	2.779	3.707
27	.684	.855	1.057	1.314	1.703	2.052	2.473	2.771	3.690
28	.683	.855	1.056	1.313	1.701	2.048	2.467	2.763	3.674
29	.683	.854	1.055	1.311	1.699	2.045	2.462	2.756	3.659
30	.683	.854	1.055	1.310	1.697	2.042	2.457	2.750	3.646
40	.681	.851	1.050	1.303	1.684	2.021	2.423	2.704	3.551
60	.679	.848	1.046	1.296	1.671	2.000	2.390	2.660	3.460
120	.677	.845	1.041	1.289	1.658	1.980	2.358	2.617	3.373
∞	.674	.842	1.036	1.282	1.645	1.960	2.326	2.576	3.291

Table 13.—*An example of ranked revegetated and reference areas, the difference between the two, and the difference squared*

Life-form or species	Revegetated area lb/acre DW	Revegetated area R_1	Reference area lb/acre DW	Reference area R_2	d_i	d_i^2
1	653	2	624	2	0	0
2	579	3	448	4	−1	1
3	334	5	591	3	2	4
4	725	1	663	1	0	0
5	451	4	297	6	−2	4
6	26	11	151	8	3	9
7	108	8	94	10	−2	4
8	342	6	225	7	−1	1
9	67	10	409	5	5	25
10	84	9	43	11	−2	4
11	131	7	123	9	−2	4
12	19	12	36	12	0	0
					$\Sigma =$	56

Similarity Indices

Indices of similarity provide a means of mathematically comparing two different plant communities. They are, in general, a function of the number of plant species or life-forms found in both communities as well as the number found in only one community or the other. In addition, certain indices of similarity (IS) incorporate the importance value of each species or life-form present in the community. Both species or life-form number and the distribution of individuals within each area are included in these indices. Similarity indices are simple and direct methods of comparing two communities, and in most cases, provide more appropriate comparisons of the diversity of reference and revegetated areas than either Shannon's diversity index or Spearman's rank correlation coefficient.

Three separate indices will be presented here. Two of the indices, Motyka and others' (1950) version of Sorensen's similarity index and Bray and Curtis' (1957) version of Sorensen's similarity index, are closely related. Bray and Curtis' version of Sorensen's similarity index is merely a computational simplification of Motyka and others' version that requires the use of percent values for each species or life form. These two versions of Sorensen's similarity index produce identical results. The general form of these indices has been endorsed by Steward (1982) for comparing the diversity of revegetated and

reference areas. The third index to be included is Spatz' (1970) modification of Jaccard's index. It has been suggested by Dr. Ed DePuit (personal communication) that Spatz' index provides a more reliable comparison of reference and revegetated communities than the modifications of Sorensen's index. The formula for each of the indices and examples of their use are provided.

Motyka's version of Sorensen's similarity index (IS_{MO}) is:

$$IS_{MO} = \frac{2\,MW}{MA + MB}$$

where

MW = Sum of the smaller importance values of the species or life-forms common to both areas

MA = The sum of the importance values of all species or life-forms in one area

MB = The sum of the importance values of all species or life-forms in the other area

The value of the index ranges from 0 to 1, with 1 being complete similarity.

Bray and Curtis' version of Sorensen's similarity index is as follows:

$$IS_{BC} = \frac{2\,MW}{200} \times 100 \quad \text{or} \quad IS_{BC} = MW(\text{percent})$$

where

MW = Sum of the smaller importance values of the species or life-forms common to both areas.

This index, as noted earlier, produces identical results to Motyka and others' version of Sorensen's similarity index. Percent values are used instead of importance values. Any differences between the indices are the result of rounding.

Spatz' modification of Jaccard's index is calculated as follows:

$$IS_{SP} = R \times \frac{MC}{MA + MB + MC} \times 100$$

where

R = The smaller values of the species or life-forms common to both areas are first divided by the greater values. These fractions are then added up and the sum is divided by the total number of species in both areas

MC = The sum of the values of all species or life-forms common to both areas

MA = The sum of the values of all species or life-forms in one area

MB = The sum of the values of all species or life-forms in the second area

This index consists of two separate parts. The first part (R) expresses the relative similarity of the two areas being compared, in terms of the number of common species and the differences in importance values between individual species. The second part is the quantitative application of Jaccard's index. It examines the relative similarity of the two areas in terms of importance values.

Tables 14, 15, and 16 are examples of the calculation of the 3 different similarity indices using both species and life-form data. The importance values used are production values (lb/acre dry weight). Table 14 shows the common and unique species of a revegetated area and a reference area and an example calculation of Motyka and others' version of Sorensen's index. Two examples using life-forms are shown in tables 15 and 16; these illustrate the effect of differences in importance values on the 3 similarity indices. Table 16 uses the same life-forms but a different apportionment of importance values.

The following considerations should be made when interpreting similarity indices:

1. The greater the difference in magnitude between the two importance values and the fewer the species or life-forms in common, the smaller the index of similarity.

2. A similarity index value of 0.80 normally indicates a high degree of similarity between two areas. The index value chosen as the lower limit for meeting the diversity criteria for the revegetated area will be dependent upon the vegetation type and the management plan for the area. One method of determining a realistic index of similarity is to sample replicate areas within the reference area and to calculate the similarity index for the replicates. This index would be a measure of the inherent similarity within the reference. A value slightly lower than the one obtained for the reference could serve as the standard of comparison for the similarity between the reference area and the revegetated area.

Table 14.—An example of the common and unique species of a revegetated and reference area and the calculation of Motyka's version of Sorensen's index

Species	Revegetated area (MA) lb/acre DW	Common species (MA) lb/acre DW	(MB)	Reference area (MB) lb/acre DW
1		553	524	
2		479	348	
3		234	441	
4		625	563	
5		351	197	
6		26	151	
7		108	94	
8		84	175	
9	67			
10	242			
11				269
12				43
13				123
14				36
Total	309			471

Calculation of Motyka and others' version of Sorensen's index.

$$IS_{MO} = \frac{2\,MW}{MA + MB}$$

$$MW = 524 + 348 + 234 + 563 + 197 + 26 + 94 + 84$$
$$= 2{,}070$$

$$MA = 553 + 479 + 234 + 625 + 351 + 26 + 108 + 84 + 67 + 242$$
$$= 2{,}769$$

$$MB = 524 + 348 + 441 + 563 + 197 + 151 + 94 + 175 + 269 + 43 + 123 + 36$$
$$= 2{,}964$$

$$IS_{MO} = \frac{2(2{,}070)}{2{,}769 + 2{,}964} = 0.72 \times 100 = 72\%$$

Table 15.—*Example of high similarity between a revegetated area and a reference area as compared by 3 similarity indices.*

Life-form		Revegetated area lb/acre DW	Percent comp.	Reference area lb/acre DW	Percent comp.
I.A	Annual grass	187	15	28	2
I.B.2.b.	Perennial cool season bunchgrass	361	29	503	36
I.B.2.a.	Perennial warm season bunchgrass	274	22	391	28
I.B.1.a.	Perennial warm season rhizomatous grass	162	13	154	11
II.A.	Annual herbs	199	16	14	1
II.B.	Perennial herbs	62	5	196	14
II.C.	Biennial herbs			28	2
III.A.1.	Broadleaf deciduous shrubs			84	6
Total		1,245	100	1,398	100

Motyka and others' version of Sorensen's index:

$$IS_{MO} = \frac{2\,MW}{MA + MB} \times 100$$

MW = 28 + 361 + 274 + 154 + 14 + 62 = 893

MA = 187 + 361 + 274 + 162 + 199 + 62 = 1,245

MB = 28 + 503 + 391 + 154 + 14 + 196 + 28 + 84 = 1,398

$$IS_{MO} = \frac{2(893)}{1,245 + 1,398} = 0.677 \times 100 = 68\%$$

Bray and Curtis' version of Sorensen's index:

IS_{BC} = MW(percent)

MW = 2 + 29 + 22 + 11 + 1 + 5 = 70

IS_{BC} = 70(percent) = 70%

Spatz' version of Jaccard's index:

$$IS_{SP} = R \times \frac{MC}{MA + MB + MC} \qquad IS_{SP} = 0.37 \times \frac{192}{200} \times 100 = 36\%$$

$$R = \frac{2 \div 15 + 29 \div 36 + 22 \div 28 + 11 \div 13 + 1 \div 16 + 5 \div 14}{8}$$

$$= \frac{0.13 + 0.80 + 0.79 + 0.85 + 0.06 + 0.36}{8} = 0.37$$

Table 16.—*Example of low similarity between a revegetated area and a reference area as compared by 3 similarity indices.*

Life-form		Revegetated area lb/acre DW	Percent comp.	Reference area lb/acre DW	Percent comp.
I.A	Annual grass	373	25	28	2
I.B.2.b.	Perennial cool season bunchgrass			483	37
I.B.2.a.	Perennial warm season bunchgrass	194	13	345	26
I.B.1.a.	Perennial warm season rhizomatous grass	448	30	148	11
II.A.	Annual herbs	433	29	13	1
II.B.	Perennial herbs	45	3	27	2
II.C.	Biennial herbs			27	2
III.A.1.	Broadleaf deciduous shrubs			80	6
Total		1,493	100	1,312	99

Motyka and others' version of Sorensen's index:

$$IS_{MO} = \frac{2\ MW}{MA + MB} \times 100$$

MW $= 28 + 194 + 148 + 13 + 45 = 428$

MA $= 373 + 194 + 448 + 433 + 45 = 1{,}493$

MB $= 28 + 483 + 345 + 148 + 13 + 188 + 27 + 80 = 1{,}312$

$$IS_{MO} = \frac{2(428)}{1{,}493 + 1{,}312} = 0.305 \times 100 = 30\%$$

Bray and Curtis' version of Sorensen's index:

IS$_{BC}$ = MW(percent)

MW $= 2 + 13 + 11 + 1 + 13 = 30$

IS$_{BC}$ = 30(percent) = 30%

Spatz' version of Jaccard's index:

$$IS_{SP} = R \times \frac{MC}{MA + MB + MC} \qquad IS_{SP} = 0.15 \times \frac{155}{200} \times 100 = 12\%$$

$$R = \frac{2 \div 25 + 13 \div 26 + 11 \div 30 + 1 \div 29 + 3 \div 14}{8}$$

$$= \frac{0.08 + 0.5 + 0.37 + 0.03 + 0.21}{8} = 0.15$$

Choice of a Similarity Index

The two types of indices, Spatz' index and Sorensen's modifications, place different amounts of emphasis on the quantitative and qualitative properties of revegetated and reference areas. In general, Spatz' index combines both quantitative and qualitative properties while Sorensen's modifications are more strictly quantitative (Mueller-Dombois and Ellenberg 1974). For example, Spatz' index places a greater emphasis on the comparison of the number of common and different species or life-forms and the differences in importance values between individual species or life forms. Comparisons of revegetated and reference areas with several common species or life-forms in which all of the common species or life-forms have large importance values generally produce high similarity values when modifications of Sorensen's index are used. However, if the same areas also have species or life-forms with smaller importance values that occur in only one or the other of the areas, Spatz' index will produce a much smaller similarity value than Sorensen's modifications (see tables 15 and 16).

Choice of an index will ultimately depend upon the objectives of the investigator. In most cases Spatz' index will provide a more rigorous comparison of two areas.

Selection of Importance Values

The selection of importance values for use with the Spearman's R_o diversity indices, or similarity indices deserves careful consideration. Productivity is normally the best measure of a species' importance; it indicates both the species' biological activity and the amount of the communities' resources that a species utilizes. The measure has little ambiguity due to collection methods and is directly comparable between species. Density, however, is an inappropriate measure in many communities because of the huge differences in the contribution of individuals of different life-forms (say, trees versus herbs) to the second area.

MEETING STATISTICAL REQUIREMENTS

The federal regulations state that "the ground cover and productivity of the revegetated area shall be considered equal if they are at least 90 percent of the ground cover and productivity of the reference area with 90 percent statistical confidence or with 80 percent statistical confidence on shrublands" (CFS 816–116). In addition, the regulations require that certain areas, depending upon the proposed management, will be stocked

with a specified number of trees or shrubs. (Refer to the Rules and Regulations, appendix I). To meet the regulation requirements, it will be necessary to: (1) calculate the number of sample observations required to achieve the specified level of confidence for each production, cover, and density sample; and (2) determine if the revegetated area has 90 percent or more of the production and cover of the reference area from a statistical confidence limit estimate. Depending upon the needs of the investigator, sample data can be summarized as: (1) total production, cover, or density in each quadrat regardless of species or life form; or (2) production, cover, or density of each species or life form within each quadrat.

The hypothesis to be examined is H_o: $(\mu_2 - .9\mu_1) \geq 0$ vs. H_A: $(\mu_2 - .9\mu_1) < 0$, where μ_2 equals the mean production, cover, or density of the revegetated area and μ_1 equals the mean production, cover, or density of the reference area. This says that the revegetated area is successfully revegetated when its mean production, cover, and density is 90 percent or greater than that of the reference area.

Required Sample Size

A two-stage procedure is used in which the final required sample size is calculated from a first stage sample drawn from both the reference and revegetated sample areas (Booth, personal communication).[1] The minimum sample size required in the first stage is calculated from an estimate of the mean and variance of the production or cover on the reference area.
GENERAL NOTATION:

n_{ij} = The size of the sample from population i (i = 1; reference area and i = 2; revegetated area), in stage j (j = 1; first stage and j = 2; second stage)

t = A t-value from the table of the t distribution (table 20)

d = The closeness with which we wish to estimate the difference of interest

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[1]Note: to adapt this procedure to changes in the regulations see Appendix VII.

$\bar{x}_i$ = Estimate of the mean from population i

s_i^2 = Estimate of the variance from population i

STEP 1. Obtain an estimate of the mean and variance of the production or cover of the reference area. This estimate can be derived from a presample or from past sampling experience. Production values should be calculated as dry weights.

Select a value for d. This value is the size of the difference we wish to detect. Ideally, this value is a predetermined standard (for example x number of pounds) that is totally independent of the mean and is chosen by the sampler on the basis of what is both acceptable and realistic.

Because of the variety of vegetation types being sampled and the large difference in production values obtained, it is unlikely that the sampler will always know what a realistic value of d is. As a rule, we suggest that d be computed as a small percentage of the mean of the reference area. For example, this value could be one-fourth, or one-half, of 1 percent of the mean of the reference area. If the revegetated area had a mean production of 90 percent of that of the reference area, the difference between the two means would be 10 percent of the mean of the reference area. This difference is the quantity of interest; 5 percent of this difference would be one-half of 1 percent of the mean of the reference area. This is the rationale for using one-fourth or one-half of 1 percent of the reference mean for d. In areas in which production values are low and variances are high, such as deserts, this method may result in the selection of a d value that is unrealistically small. Experience in the sampling of different vegetation types should aid the investigator in selecting realistic d values.

The relationship of d and the variance (s^{*2}, initial estimate or guess of the variance of the reference area) to sample size (n) is shown in tables 17 and 18. As d decreases, sample size increases, and as the variance increases, sample size increases. The values presented in tables 17 and 18 are to be used only as a guide for the selection of d and n. A caution: too small a sample size in the first stage will result in a large sample size in the second stage.

Table 17.—*Values of d for selected variances and sample sizes*

Sample size	Variance																		
	100	200	300	400	500	600	700	800	900	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
10	6.97	9.86	12.07	13.94	15.59	17.08	18.44	19.72	20.91	22.05	31.18	38.18	44.09	49.30	54.00	58.33	62.35	66.14	69.71
20	4.93	6.97	8.54	9.86	11.02	12.07	13.04	13.94	14.79	15.59	22.05	27.00	31.18	34.86	38.18	41.24	44.09	46.77	49.30
30	4.02	5.69	6.97	8.05	9.00	9.86	10.65	11.38	12.07	12.73	18.00	22.05	25.46	28.46	31.18	33.67	36.00	38.18	40.25
40	3.49	4.93	6.04	6.97	7.79	8.54	9.22	9.86	10.46	11.02	15.59	19.09	22.05	24.65	27.00	29.16	31.18	33.07	34.86
50	3.12	4.41	5.40	6.24	6.97	7.64	8.25	8.82	9.35	9.86	13.94	17.08	19.72	22.05	24.15	26.08	27.89	29.58	31.18
60	2.85	4.02	4.93	5.69	6.36	6.97	7.53	8.05	8.54	9.00	12.73	15.59	18.00	20.12	22.05	23.81	25.46	27.00	28.46
80	2.46	3.49	4.27	4.93	5.51	6.04	6.52	6.97	7.39	7.79	11.02	13.50	15.59	17.43	19.09	20.62	22.05	23.38	24.65
100	2.20	3.12	3.82	4.41	4.93	5.40	5.83	6.24	6.61	6.97	9.86	12.07	13.94	15.59	17.08	18.44	19.72	20.91	22.05
150	1.80	2.55	3.12	3.60	4.02	4.41	4.76	5.09	5.40	5.69	8.05	9.86	11.38	12.73	13.94	15.06	16.10	17.08	18.00
200	1.56	2.20	2.70	3.12	3.49	3.82	4.12	4.41	4.68	4.93	6.92	8.54	9.86	11.02	12.07	13.04	13.94	14.79	15.59
250	1.39	1.97	2.41	2.79	3.12	3.42	3.69	3.94	4.18	4.41	6.24	7.64	8.82	9.86	10.80	11.67	12.42	13.23	13.94
500	.99	1.39	1.71	1.97	2.20	2.41	2.61	2.79	2.96	3.12	4.41	5.40	6.24	6.97	7.64	8.25	8.82	9.35	9.86
1,000	.70	.99	1.21	1.39	1.56	1.71	1.84	1.97	2.09	2.20	3.12	3.82	4.41	4.93	5.40	5.83	6.24	6.61	6.97
3,000	.40	.57	.70	.80	.90	.99	1.06	1.14	1.21	1.27	1.80	2.20	2.55	2.85	3.12	3.37	3.60	3.82	4.02
5,000	.31	.44	.54	.62	.70	.76	.82	.88	.94	.99	1.39	1.71	1.97	2.20	2.41	2.61	2.79	2.96	3.12
10,000	.22	.31	.38	.44	.49	.54	.58	.62	.66	.70	.99	1.21	1.39	1.56	1.71	1.84	1.97	2.09	2.20
20,000	.16	.22	.27	.31	.35	.38	.41	.44	.47	.49	.70	.85	.99	1.10	1.21	1.30	1.39	1.48	1.56
30,000	.13	.18	.22	.25	.28	.31	.34	.36	.38	.40	.57	.70	.80	.90	.99	1.06	1.14	1.21	1.27
50,000	.10	.14	.17	.20	.22	.24	.26	.28	.30	.31	.44	.54	.62	.70	.76	.82	.88	.94	.99

Table 18.—Sample sizes for selected variances and d values

d	100	200	300	400	500	600	700	800	900	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
1	486	972	1,458	1,944	2,430	2,916	3,402	3,888	4,374	4,860	9,720	14,580	19,440	24,300	29,160	34,020	38,880	43,740	48,600
2	122	243	365	486	608	729	851	972	1,094	1,215	2,430	3,645	4,860	6,075	7,290	8,505	9,720	10,935	12,150
3	54	108	162	216	270	324	378	432	486	540	1,080	1,620	2,160	2,700	3,240	3,780	4,320	4,860	5,400
4	30	61	91	122	152	182	213	243	273	304	608	911	1,215	1,519	1,823	2,126	2,430	2,734	3,038
5	19	39	58	78	97	117	136	156	175	194	389	538	778	972	1,166	1,361	1,555	1,750	1,944
6	14	27	41	54	68	81	95	108	122	135	270	405	540	675	810	945	1,080	1,215	1,350
7	10	20	30	40	50	60	69	79	89	99	198	298	397	496	595	694	793	893	992
8	8	15	23	30	38	46	53	61	68	76	152	228	304	380	456	532	608	683	759
9	6	12	18	24	30	36	42	48	54	60	120	180	240	300	360	420	480	540	600
10	5	10	15	19	24	29	34	39	44	49	97	146	194	243	292	340	389	437	486
15	2	4	6	9	11	13	15	17	19	22	43	65	86	108	130	151	173	194	216
20	1	2	4	5	6	7	9	10	11	12	24	36	49	61	73	85	97	109	122
25	1	2	2	3	4	5	5	6	7	8	16	23	31	39	47	54	62	70	78
30	1	1	2	2	3	3	4	4	5	5	11	16	22	27	32	38	43	49	54
35	0	1	1	2	2	2	3	3	4	4	8	12	16	20	24	28	32	36	40
40	0	1	1	1	2	2	2	2	3	3	6	9	12	15	18	21	24	27	30
45	0	0	1	1	1	1	2	2	2	2	5	7	10	12	14	17	19	22	24
50	0	0	1	1	1	1	1	2	2	2	4	6	8	10	12	14	16	17	19
60	0	0	0	1	1	1	1	1	1	1	3	4	5	7	8	9	11	12	14
70	0	0	0	0	0	1	1	1	1	1	2	3	4	5	6	7	8	9	10
80	0	0	0	0	0	0	1	1	1	1	2	2	3	4	5	5	6	7	8
90	0	0	0	0	0	0	0	0	1	1	1	2	2	3	4	4	5	5	6
100	0	0	0	0	0	0	0	0	0	0	1	1	2	2	3	3	4	4	5

STEP 2. Compute the **minimum** required sample size from the reference area as

$$n_{11} = (.81)t^2 s^{*2}/d^2 \qquad \text{(eq. 1)}$$

A value of 2.0 can be used for t in the initial estimate of sample size, unless s^{*2} was derived from an actual sample. The t value should have (n–1) degrees of freedom and a probability of 0.1, where n is the actual sample size. The sample taken should be about 1.5 to 2 times this value for the first stage. Unless there is good reason to do otherwise, this would also be a reasonable value for the first stage samples size from the revegetated area. If too few first stage samples are taken, the investigator may be required to take more second stage samples than necessary from the revegetated area.

STEP 3. Obtain the random first stage samples from the reference and revegetated areas. Compute:

$\bar{x}_{11}$ and s_1^2 from the reference area

$\bar{x}_{21}$ and s_2^2 from the revegetated area

$$s^2 = [(n_{11} - 1)s_1^2 + (n_{21} - 1)s_2^2]/(n_{11} + n_{21} - 2) \qquad \text{(eq. 2)}$$

= pooled variance from the reference and revegetated areas.

An example calculation of $\bar{x}$, and s_1^2 is given in table 19.

Table 19.—Sample calculation of the mean, $\bar{x}$, and variance, s^2, for a hypothetical reference area

Quadrat number	Reference area x(gms dry wt)	x^2
1	82	6,724
2	94	8,836
3	88	7,744
4	116	13,456
5	88	7,744
6	120	14,400
7	104	10,816
8	85	7,225
9	102	14,400
10	92	8,464
11	106	11,236
12	94	8,836
sum(Σ)	1,189	119,881

$$\bar{x} = \frac{\text{sum of } x}{\text{total number quadrats}} = \frac{1189}{12} = 99.08$$

$$s^2 = \frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n-1} = \frac{119,881 - \frac{(1189)^2}{12}}{11} = 188.26$$

STEP 4. Determine the required sample size from the revegetated area for the second stage sample. Find a value with a one-tailed t distribution that has $(n_{11} + n_{21} - 2)$ degrees of freedom and a probability of 0.1 (table 20). Compute:

$$A = n_{11}t^2s^2 \qquad \text{(eq. 3)}$$

$$B = n_{11}d^2 - (.81)t^2s^2 \qquad \text{(eq. 4)}$$

$$n_{22} = A/B - n_{21} \qquad \text{(eq. 5)}$$

STEP 5.

A. If n_{22} is negative, no further samples are required. Go to the revegetated and reference area comparison.

B. If n_{22} is a reasonable sample size for the revegetated area, then an additional sample of that size should be obtained from the revegetated area for the second stage. A second stage sample from the reference area is not needed. After the second sample has been taken, go to the revegetated and reference area comparison.

C. If n_{22} is unreasonably large, then further sampling from both the revegetated and the reference areas will be required. A sample size of n_{22} will be selected for both the reference and revegetated areas and will be calculated as:

$$n_2 = [1.81 \, t^2s^2]/d^2 - n_1 \qquad \text{(eq. 6)}$$

It is assumed that the first-stage sample size was the same for both the reference and revegetated areas, namely $n_{11} = n_{21} = n_1$. The value of t has $(n_{11} + n_{21} - 2)$ degrees of freedom and a probability of 0.1, $s^2 =$ the pooled variance calculated from equation 2, and $d =$ the value selected in STEP 1.

Consider $n_{12} = n_{22} = n_2$, collect a sample of size n_2 from both the reference and revegetated areas, and go to the revegetated and reference area comparison.

Table 20.—Values with a one-tailed t- distribution for various levels of n, or degrees of freedom, d.f.

df	0.2	0.15	0.1	0.05	0.25
1	1.376	1.963	3.078	6.314	12.706
2	1.061	1.386	1.886	2.920	4.303
3	.978	1.250	1.638	2.353	3.182
4	.941	1.190	1.533	2.132	2.776
5	.920	1.156	1.476	2.015	2.571
6	.906	1.134	1.440	1.943	2.447
7	.896	1.119	1.415	1.895	2.365
8	.889	1.108	1.397	1.860	2.306
9	.883	1.100	1.383	1.833	2.262
10	.879	1.093	1.372	1.812	2.228
11	.876	1.088	1.363	1.796	2.201
12	.873	1.083	1.356	1.782	2.179
13	.870	1.079	1.350	1.771	2.160
14	.868	1.076	1.345	1.761	2.145
15	.866	1.074	1.341	1.753	2.131
16	.865	1.071	1.337	1.746	2.120
17	.863	1.069	1.333	1.740	2.110
18	.862	1.067	1.330	1.734	2.101
19	.861	1.066	1.328	1.729	2.093
20	.860	1.064	1.325	1.725	2.086
21	.859	1.063	1.323	1.721	2.080
22	.858	1.061	1.321	1.717	2.074
23	.858	1.060	1.319	1.714	2.069
24	.857	1.059	1.318	1.711	2.064
25	.856	1.058	1.316	1.708	2.060
26	.856	1.058	1.315	1.706	2.056
27	.855	1.057	1.314	1.703	2.052
28	.855	1.056	1.313	1.701	2.048
29	.854	1.055	1.311	1.699	2.045
30	.854	1.055	1.310	1.697	2.042
40	.851	1.050	1.303	1.684	2.021
60	.848	1.046	1.296	1.671	2.000
120	.845	1.041	1.289	1.658	1.980
∞	.842	1.036	1.282	1.645	1.960

Revegetated and Reference Area Comparison

The reference area and revegetated area comparison will be based upon a lower confidence limit for $(\mu_2 - .9\mu_1)$. This analysis is similar to a test of hypothesis (such as a t-test) in that it tells the investigator if the cover and production of the revegetated area is 90 percent of the reference area with the specified level of confidence. In addition, it allows the investigator to determine how many units (lbs/acre or kg/ha) the revegetated area deviates from the required 90 percent of the production or cover of the reference area with the specified level of confidence.

STEP 6. Compute the weighted mean for all of the samples taken. If first and second stage samples were taken in both the revegetated and reference areas:

$$\bar{x}.. = w_1\bar{x}_{11} + w_2\bar{x}_{21} + w_3\bar{x}_{12} + w_4\bar{x}_{22} \qquad \text{(eq. 7)}$$

where

$w_1 = (-.9)n_{11}/n_{1.}$

$w_2 = n_{21}/n_{2.}$

$w_3 = (-.9)n_{12}/n_{1.}$

$w_4 = n_{22}/n_{2.}$

$n_{1.} = n_{11} + n_{12}$

$n_{2.} = n_{21} + n_{22}$

If the sample size requirement was met in the first stage sample:

$$\bar{x}.. = -.9\bar{x}_{11} + (1)\bar{x}_{21} \qquad \text{(eq. 8)}$$

If second stage samples were taken in only the revegetated areas:

$$\bar{x}.. = w_1\bar{x}_{11} + w_2\bar{x}_{21} + w_4\bar{x}_{22} \qquad \text{(eq. 9)}$$

STEP 7. The confidence limit is calculated using:

$$\bar{x}.. \pm t\,C \qquad \text{(eq. 10)}$$

where

t = a value from the t table (table 20) with $n_{11} + n_{21}$ − 2 degrees of freedom and a probability of 0.1.

$C = \sqrt{(.81/n_{1.} + 1/n_{2.})s^2}$

s^2 = the pooled variance from the first stage results (eq. 2).

STEP 8. The interpretation of the confidence interval estimate is as follows:

Lower limit	Conclusion
positive	$\mu_2 > .9\mu_1$
negative	$\mu_2 < .9\mu_1$

If the value of the confidence limit is positive, the revegetated area has met the requirement specified in the regulations. If the confidence limit is negative, the revegetated area has not met the requirement.

Example 1

STEP 1. Suppose we estimate from past sampling experience that the reference area has a mean of 3,600 lb/acre and a variance of 1960. A d value is chosen as a small fraction, one-half, of 1 percent of this reference area mean. This value is $36 \div 2 = 18$.

STEP 2. Compute the **minimum** required sample size from the reference area using equation 1:

$n_{11} = (.81)(2.0^2)(1960)/18^2$

$= 6350.4/324$

$= 19.6$

where t is estimated as 2.0.

Multiply the value of n_{11} obtained above by 1.5 or 2 to obtain the number of first stage random samples. In this case, 30 to

40 samples would be taken from both the reference and revegetated areas.

STEP 3. For 40 samples from both areas, we compute the following values. Calculation of $\bar{x}$ and s_i^2 is illustrated in table 19.

Calculate s^2 from equation 2.

$\bar{x}_{11} = 3322$ lb/acre $s_1^2 = 1915$

$\bar{x}_{21} = 3018$ lb/acre $s_2^2 = 2250$

$s^2 = [(40-1)1915 + (40-1)2250]/(40+40-2)$

$= 162435/78$

$= 2082.5$

STEP 4. Look up t with $(40+40-2)$ degrees of freedom and a probability of 0.1 (table 20). Compute using equations 3, 4, and 5:

$A = (40)(1.29^2)(2082.5)$

$= 138619.5$

$B = 40(18^2) - (.81)(1.29^2)(2082.5)$

$= 10153.0$

$n_{22} = \dfrac{138619.5}{10153.0} - 40$

$= -26.3$

STEP 5. Interpretation: Since n_{22} is negative, no further samples are needed.

STEP 6. Compute the weighted mean using equation 8.

$\bar{x}.. = (-.9)(3322) + (1)3081$

$= 91.2$

STEP 7. Calculate the confidence limit using equation 10.

$\bar{x}.. - (1.29)(9.7)$

$\bar{x}.. - 12.5$

where

t = 1.29 for $(40+40-2)$ degrees of freedom and a probability of 0.1

$C = \sqrt{(.81/40 + 1/40)2082.5}$

$= 9.7$

The confidence limit is

$91.2 - 12.5 = 78.7$

STEP 8. Interpretation: Since the limit is positive, we conclude that the mean value of the revegetated area was more than 90 percent of the mean value of the reference area. The revegetated area has met the requirement for successful revegetation, but more information is available. The revegetated area yields at least 79 lb/acre more than the critical 90 percent of the reference area yield (90 percent confidence).

Example 2

STEP 1. We estimate that the reference area has a mean of 2,200 lb/acre and a variance of 500. A value for d is chosen as one-half of 1 percent of the reference area mean. The d value is $22 \div 2 = 11$.

STEP 2. Compute the **minimum** required sample size from the reference area using equation 1.

$n_{11} = (.81)(2.0^2)(500)/11^2$

$= 13.4$

where a t value of 2.0 is used.

The value of n_{11} is multiplied by 1.5 or 2 to obtain the number of first stage random samples. The number of samples to be taken from both the reference and revegetated areas is 20 to 27.

STEP 3. Obtain 27 samples from both areas and compute the following values. Calculation of $\bar{x}$ and s_i^2 is illustrated in table 19.

Calculate s^2 from equation 2.

x_{11} = 2243 lb/acre s_1^2 = 1630

x_{21} = 2031 lb/acre s_2^2 = 2462

s^2 = [(27 − 1)1630 + (27 − 1)2462]/27 + 27 − 2)

= 106392/52

= 2046

STEP 4. Look up t with (27 + 27 − 2) degrees of freedom and a probability of 0.1. Compute using equations 3, 4, and 5:

A = 27(1.30²)(2046)

= 93359.0

B = 27(11²) − (.81)(1.30²)(2046)

= 3267 − 2800.8

= 466.2

$n_{22} = \dfrac{93359.0}{466.2} - 27$

= 173.3

STEP 5. We judge n_{22} to be unreasonably large. Additional samples are required from both the reference and revegetated areas. A sample size of n_2 is taken from each of the reference and revegetated areas, where n_2 is calculated from equation 6:

n_2 = [1.81(1.30²)(2046)]/(11²) − 27

= 51.7 − 27

= 25

Consider $n_{12} = n_{22} = n_2$

STEP 6. Compute the means of the reference and the revegetated area obtained from the second stage sample, n_2.

$\bar{x}_{12}$ = 2197 $\bar{x}_{22}$ = 1990

Then compute the weighted mean for all sample means from both stages from equation 7.

$\bar{x}..$ = (− .47)2243 + (.52)2031 + (− .43)2197 + (.48)1990

= − 1054.2 + 1056.1 − 944.7 + 955.2

= 12.4

where

w_1 = (− .9)27/52 = −.47

w_2 = 27/52   = .52

W_3 = (− .9)25/52 = −.43

w_4 = 25/52   = .48

$n_1.$ = 27 + 25   = 52

$n_2.$ = 27 + 25   = 52

STEP 7. Calculate the confidence limit from equation 10.

$\bar{x}..$ − 1.30(8.4)

$\bar{x}..$ − 11.0

where

t = 1.30 for (27 + 27 − 2) degrees of freedom and a probability of 0.1.

$C = \sqrt{(.81/52 + 1/52)2046}$

= 8.4

where s^2 is the value computed from the first stage results. The confidence limit is:

12.4 − 11.0 = 1.4

STEP 8. Interpretation: Because the limit is positive, the revegetated area has met the requirement for successful revegetation. The revegetated area yields 1.4 lb/acre more than the critical 90 percent of the reference area yield (90 percent confidence).

Example 3

STEP 1. We estimate that the reference area has a mean of 1500 lb/acre and a variance of 400. A value for d is selected as one-half 1 percent of the reference area mean. The d value is 15 ÷ 2 = 8.

STEP 2. Compute the **minimum** sample size needed from the reference area using equation 1.

n_{11} = (.81)(2.0²)(400)/8²

= 1296/64

= 20.3

where t = 2.0

Multiply n_{11} by 1.5 or 2 to determine the number of first stage random samples. In this case, 30 to 40 samples should be taken from both the reference and revegetated areas.

STEP 3. 40 samples are obtained from both areas. Compute from table 19 and equation 2.

$\bar{x}_{11}$ = 1743 s_1^2 = 752

$\bar{x}_{21}$ = 1318 s_2^2 = 1114

s^2 = (40 − 1)(752) + (40 − 1)(1114)/(40 + 40 − 2)

= 72774/78

= 933.0

STEP 4. Find t with (40 + 40 − 2) degrees of freedom and a probability of 0.1. Compute using equations 3, 4, and 5.

A = 40(1.29²)(933.0)

= 62104.2

B = 40(8²) − (.81)(1.29²)(933.0)

= 2560 − 1257.6

= 1302.4

$n_{22} = \dfrac{62104.2}{1302.4} - 40$

= 47.7 − 40

= 7.7 or 8

STEP 5. The value of n_{22} is a reasonable sample size for the revegetated area. An additional sample of size 8 is obtained from the revegetated area, for the second stage.

STEP 6. The mean of the revegetated area for the second stage sample is computed to be 1,352. Next, compute the weighted mean for all sample means from both stages using equation 9.

$\bar{x}..$ = (− .9)(1743) + (.83)(1318) + (.17)(1352)

= − 1568.7 + 1093.9 + 229.8

= − 245.0

where

w_1 = (− .9)40/40 = − .9

w_2 = 40/48   = .83

w_4 = 8/48   = .17

$n_1.$ = 40 + 0   = 40

$n_2.$ = 40 + 8   = 48

STEP 7. Calculate the confidence limit using equation 10.

$\bar{x}.. - 1.29(6.2)$

$\bar{x}.. - 8.0$

where

t = 1.29 for $(40 + 40 - 2)$ degrees of freedom and a probability of 0.1.

$C = \sqrt{[(.81/40) + (1/48)]933.0}$

$= 6.2$

where s^2 is the value computed from the first stage results. The confidence limit estimate is:

$-245.0 - 8.0 = -253.0$

STEP 8. Interpretation: Since the limit is negative, the revegetated area did not meet the requirement for successful revegetation. The revegetated area may yield as much as 253 lb/acre less than the critical 90 percent of the reference area (90 percent confidence).

Additional Considerations

If the statistical tests reveal that the revegetated area has not met the criteria for successful revegetation, it may be desirable to examine the possible causes.

1. Error resulting in data that does not represent the true populations (lacks accuracy) and/or that is not repeatable (lacks precision) could play a large part in arriving at a false conclusion when testing hypotheses or examining confidence limits. Error can manifest itself in several ways. The sample unit chosen may not have been representative of the vegetation type being selected for, or the sample unit may have been located on an ecotone or transition between vegetation types. Potentially this could increase the variability of the sample within a single sample unit as well as between the two sample units. In addition, the sampling methods selected may have been inappropriate for the vegetation type or site conditions. Finally, the collection and analysis of the data may have been biased or may have lacked precision. This could greatly increase the variability of data.

Error can easily be compounded. Each error has the ability to increase the magnitude of subsequent errors. If error is suspected, it may be necessary for the investigator to revise the sampling scheme.

2. The investigator may have chosen an unrealistic value of d, the acceptable amount of difference between the means. It may be necessary to try several different d values to find the one that best fits the sampling situations. In vegetation types with a high degree of inherent variability, the requirement that the mean production and cover of the vegetated area be within 90 percent of that of the reference area may be unrealistic in terms of the large numbers of samples required and the high degree of similarity needed between the reference and revegetated areas. However, unless the regulations are changed, the required percentage of the reference area mean cannot be changed.

The confidence level (α value) should not be lowered. The confidence level determines the amount of faith, or confidence, that the investigator can have in his estimate of cover, density, or production, and it is necessary to have a high degree of confidence in this estimate in order to draw valid conclusions.

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occurring vegetation during each season of the year.

(4) If both the premining and postmining land uses are cropland, planting of the crops normally grown will meet the requirements of Paragraph (b)(1) of this Section.

§ 816.112 Revegetation: Use of introduced species.

Introduced species, may be substituted for native species only if approved by the regulatory authority under the following conditions:

(a) After appropriate field trials have demonstrated that the introduced species are desirable and necessary to achieve the approved postmining land use;

(b) The species are necessary to achieve a quick, temporary, and stabilizing cover that aids in controlling erosion; and measures to establish permanent vegetation are included in the approved plan submitted under Sections 780.18(b)(3) and 780.23.

(c) The species are compatible with the plant and animal species of the region;

(d) The species meet the requirements of applicable State and Federal seed or introduced species statutes and are not poisonous or noxious.

§ 816.113 Revegetation: Timing.

Seeding and planting of disturbed areas shall be conducted during the first normal period for favorable planting conditions after final preparation. The normal period for favorable planting shall be that planting time generally accepted locally for the type of plant materials selected. When necessary to effectively control erosion, any disturbed area shall be seeded and planted, as contemporaneously as practicable with the completion of backfilling and grading, with a temporary cover of small grains, grasses, or legumes until a permanent cover is established.

§ 816.114 Revegetation: Mulching and other soil stabilizing practices.

(a) Suitable mulch and other soil stabilizing practices shall be used on all regraded and topsoiled areas to control erosion, promote germination of seeds, or increase the moisture-retention capacity of the soil. The regulatory authority may, on a case-by-case basis, suspend the requirement for mulch, if the permittee can demonstrate that alternative procedures will achieve the requirements of 816.116 and do not cause or contribute to air or water pollution.

(b) When required by the regulatory authority, mulches shall be mechanically or chemically anchored to the soil surface to assure effective protection of the soil and vegetation.

(c) Annual grasses and grains may be used alone, as in situ mulch, or in conjunction with another mulch, when the regulatory authority determines that they will provide adequate soil erosion control and will later be replaced by perennial species approved for the postmining land use.

(d) Chemical soil stabilizers alone, or in combination with appropriate mulches, may be used in conjunction with vegetative covers approved for the postmining land use.

§ 816.115 Revegetation: Grazing.

When the approved postmining land use is range or pasture land, the reclaimed land shall be used for livestock grazing at a grazing capacity approved by the regulatory authority approximately equal to that for similar non-mined lands, for at least the last two full years of liability required under Section 816.116(b).

§ 816.116 Revegetation: Standards for success.

(a) Success of revegetation shall be measured by techniques approved by the regulatory authority after consultation with appropriate State and Federal agencies. Comparison of ground cover and productivity may be made on the basis of reference areas or through the use of technical guidance procedures published by USDA or USDI for assessing ground cover and productivity. Management of the reference area, if applicable, shall be comparable to that which is required for the approved postmining land use of the permit area.

(b) (1) Ground cover and productivity of living plants on the revegetated area within the permit area shall be equal to the ground cover and productivity of living plants on the approved reference area or to the standards in other technical guides approved by the Director for use in the regulatory program. The period of extended responsibility under the performance bond requirements of Subchapter J initiates when ground cover equals the approved standard after the last year of augmented seeding, fertilizing, irrigation or other work which ensures success in—

(i) Areas of more than 26.0 inches average annual precipitation; and continues for not less than five years. Ground cover and productivity shall equal the approved standard for the last two consecutive years of the responsibility period; or in

(ii) Areas of less than or equal to 26.0 inches average annual precipitation; and continues for not less than 10 years. Ground cover and productivity shall equal the approved standard for the last two consecutive years of the responsibility period.

§ 816.111 Revegetation: General requirements.

(a) Each person who conducts surface mining activities shall establish on all affected land a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area of disturbed land or species that supports the approved postmining land use. For areas designated as prime farmland, the requirements of 30 CFR 823 shall apply.

(b) All revegetation shall be in compliance with the plans submitted under 30 CFR 780.18 and 780.23, as approved by the regulatory authority in the permit, and carried out in a manner that encourages a prompt vegetative cover and recovery of productivity levels compatible with the approved postmining land use.

(1) All disturbed land, except water areas and surface areas of roads that are approved as a part of the postmining land use, shall be seeded or planted to achieve a permanent vegetative cover of the same seasonal variety native to the area of disturbed land.

(2) The vegetative cover shall be capable of stabilizing the soil surface from erosion.

(3) Vegetative cover shall be considered of the same seasonal variety when it consists of a mixture of species of equal or superior utility for the approved postmining land use, when compared with the utility of naturally-

(2) For purposes of paragraph (b)(1) of this Section, the average annual precipitation can be determined either—

(i) By interpolation, using standard techniques, from 'Mean Annual Precipitations,' Map, p. 97, The National Atlas of the United States, U.S. Department of the Interior, Geological Survey, 1970; or from 'Climatic Atlas of the United States,' U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration, 1974; or from long-term precipitation averages from 'Climatological Data,' U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration; or from other official records; or

(ii) Based on 10 years of continuous and reliable precipitation records from stations located in or adjacent to the mine plan area.

(3) The ground cover and productivity of the revegetated area shall be considered equal if they are at least 90 percent of the ground cover and productivity of the reference area with 90 percent statistical confidence, or with 80 percent statistical confidence on shrublands, or ground cover and productively are at least 90 percent of the standards in a technical guide approved pursuant to 30 CFR 816.116(b)(1). Exceptions may be authorized by the regulatory authority under the following standards:

(i) For previously mined areas that were not reclaimed to the requirements of this Subchapter, as a minimum the ground cover of living plants shall not be less than can be supported by the best available topsoil or other suitable material in the reaffected area, shall not be less than the ground cover existing before redisturbance, and shall be adequate to control erosion;

(ii) For areas to be developed for industrial or residential use less than 2 years after regrading is completed, the ground cover of living plants shall not be less than required to control erosion; and

(iii) For areas to be used for cropland, success in revegetation of cropland shall be determined on the basis of crop production from the mined area as compared to approved reference areas or other technical guidance procedures. Crop production from the mined area shall be equal to or greater than that of the approved standard for the last two consecutive growing seasons of the 5 or 10 year liability period established in (b)(1) of this Section. The applicable 5 or 10 year period of responsibility for revegetation shall commence at the date of initial planting of the crop being grown. Production shall not be considered equal if it is less than 90 percent of the production of the approved stand-

ard with 90 percent statistical confidence.

(iv) On areas to be developed for fish and wildlife management or forestland, success of vegetation shall be determined on the basis of tree, shrub or half-shrub stocking and ground cover. The tree, shrub, or half-shrub stocking shall meet the standards described in Section 816.117. The area seeded to a ground cover shall be considered acceptable if it is at least 70 percent of the ground cover of the reference areas with 90 percent statistical confidence or if the ground cover is determined to be adequate to control erosion by the regulatory authority. Section 816.116(b) shall determine the responsibility period and the frequency of ground cover measurement.

(c) The person who conducts surface mining activities shall—

(1) Maintain any necessary fences and proper management practices; and

(2) Conduct periodic measurements of vegetation, soils, and water prescribed or approved by the regulatory authority, to identify conditions during the applicable period of liability specified in Paragraph (b) of this Section.

(d) For permit areas 40 acres or less in size, in locations with an average annual precipitation of more than 26 inches, the following performance standards, if approved by the regulatory authority, may be used instead of reference areas to measure success of revegetation on sites that are disturbed. These standards shall be met for a minimum of 5 full consecutive years.

(1) Areas planted only in herbaceous species shall sustain a vegetative ground cover of 70 percent for 5 full consecutive years.

(2) Areas planted with a mixture of herbaceous and woody species shall sustain a herbaceous vegetative ground cover of 70 percent for 5 full consecutive years and 400 woody plants per acre after 5 years. On steep slopes, the minimum number of woody plants shall be 600 per acre.

(3) For purposes of this Section, herbaceous species means grasses, legumes, and nonleguminous forbs; woody plants means woody shrubs, trees and vines; and ground cover means the area of ground covered by the combined aerial parts of vegetation and the litter that is produced naturally onsite, expressed as a percentage of the total area of measurement.

§ 816.117 Revegetation: Tree and shrub stocking for forest land.

This Section sets forth forest resource conservation standards for reforestation operations to ensure that a cover of commercial tree species, noncommercial tree species, shrubs or half

shrubs, sufficient for adequate use of the available growing space, is established after surface mining activities.

(a) Stocking, i.e. the number of stems per unit area, will be used to determine the degree to which space is occupied by well-distributed, countable trees, shrubs or half-shrubs.

(1) Root crown or root sprouts over 1 foot in height shall count as one toward meeting the stocking requirements. Where multiple stems occur only the tallest stem will be counted.

(2) A countable tree or shrub means a tree that can be used in calculating the degree of stocking under the following criteria:

(i) the tree or shrub shall be in place at least 2 growing seasons,

(ii) the tree or shrub shall be alive and healthy, and

(iii) the tree or shrub shall have at least one third of its length in live crown.

(3) Rock areas, permanent road and surface water drainage ways on the revegetated area shall not require stocking.

(b) The following are the minimum performance standards for areas where commercial forest land is the approved postmining land use:

(1) The area shall have a minimum stocking of 450 trees or shrubs per acre,

(2) A minimum of 75 percent of countable trees or shrubs shall be commercial trees species,

(3) The number of trees or shrubs and the ground cover shall be determined using procedures described in Sections 816.116(b)(3)(iv) and 816.117(a) and the sampling method approved by the regulatory authority; when the stocking is equal to or greater than 450 trees or shrubs per acre and there is acceptable groundcover, the 5 or 10 year responsibility period required in Section 816.116(b) shall begin;

(4) Upon expiration of the 5 or 10 year responsibility period and at the time of request for bond release, each permittee shall provide documentation showing that the stocking of trees and shrubs and the groundcover on the revegetated area satisfy Sections 816.116(b)(3)(iv) and 816.117(c)(i).

(c) The following are the minimum performance standards for areas where woody plants are used for wildlife management, recreation, shelter belts, or forest uses other than commercial forest land:

(1) An inventory of trees, half-shrubs and shrubs shall be conducted on established reference areas according to methods approved by the regulatory authority; this inventory shall contain but not be limited to—

(i) site quality,

(ii) stand size,

(iii) stand condition,

(iv) site and species relations, and

(v) appropriate forest land utilization considerations.

(2) The stocking of trees, shrubs, half-shrubs and the groundcover established on the revegetated area shall approximate the stocking and ground cover on the reference area and shall utilize local and regional recommendations regarding species composition, spacing and planting arrangement. The stocking of live woody plants shall be equal to or greater than 90 percent of the stocking of woody plants of the same life form on the reference area. When this requirement is met and acceptable ground cover is achieved, the 5 or 10 year responsibility period required in Section 816.116(b) shall begin.

(3) Upon expiration of the 5 or 10 year responsibility period and at the time of request for bond release, each permittee shall provide documentation showing that:

(i) the woody plants established on the revegetated site are equal to or greater than 90 percent of the stocking of live woody plants of the same life form of the approved reference areas with 80 percent statistical confidence and

(ii) the groundcover on the revegetated area satisfies Section 816.116(b)(3)(iv). Species diversity, seasonal variety and regenerative capacity of the vegetation of the revegetated area shall be evaluated on the basis of the results which could reasonably be expected using the revegetation methods described in the mining and reclamation plan.

§ 816.131 Cessation of operations: Temporary.

(a) Each person who conducts surface mining activities shall effectively secure surface facilities in areas in which there are no current operations, but in which operations are to be resumed under an approved permit. Temporary abandonment shall not relieve a person of their obligation to comply with any provisions of the approved permit.

(b) Before temporary cessation of mining and reclamation operations for a period of thirty days or more, or as soon as it is known that a temporary cessation will extend beyond 30 days, persons who conduct surface mining activities shall submit to the regulatory authority a notice of intention to cease or abandon mining and reclamation operations. This notice shall include a statement of the exact number of acres which will have been affected in the permit area, prior to such temporary cessation, the extent and kind of reclamation of those areas which will have been accomplished, and identification of the backfilling, regrading, revegetation, environmental monitor-

ing, and water treatment activities that will continue during the temporary cessation.

§ 816.132 Cessation of operations: Permanent.

(a) Persons who cease surface mining activities permanently shall close or backfill or otherwise permanently reclaim all affected areas, in accordance with this Chapter and the permit approved by the regulatory authority.

(b) All underground openings, equipment, structures, or other facilities not required for monitoring, unless approved by the regulatory authority as suitable for the postmining land use or environmental monitoring, shall be removed and the affected land reclaimed.

§ 816.133 Postmining land use.

(a) *General.* All affected areas shall be restored in a timely manner —

(1) To conditions that are capable of supporting the uses which they were capable of supporting before any mining; or

(2) To higher or better uses achievable under criteria and procedures of this Section.

(b) *Determining pre-mining use of land.* The pre-mining uses of land to which the postmining land use is compared shall be those uses which the land previously supported, if the land had not been previously mined and had been properly managed.

(1) The postmining land use for land that has been previously mined and not reclaimed shall be judged on the basis of the highest and best use that can be achieved and is compatible with surrounding areas.

(2) The postmining land use for land that has received improper management shall be judged on the basis of the pre-mining use of surrounding lands that have received proper management.

(3) If the premining use of the land was changed within 5 years of the beginning of mining, the comparison of postmining use to premining use shall include a comparison with the historic use of the land as well as its use immediately preceding mining.

(c) *Prior to the release of lands from the permit area* in accordance with 807.12(c) the permit area shall be restored, in a timely manner, either to conditions capable of supporting the uses they were capable of supporting before any mining or to conditions capable of supporting approved alternative land uses. Alternative land uses may be approved by the regulatory authority after consultation with the landowner or the land-management agency having jurisdiction over the lands, if the following criteria are met:

(1) The proposed postmining land use is compatible with adjacent land use and, where applicable, with existing local, State, or Federal land use policies and plans: A written statement of the views of the authorities with statutory responsibilities for land use policies and plans is submitted to the regulatory authority within 60 days of notice by the regulatory authority and before surface mining activities begin. Any required approval, including any necessary zoning or other changes required for land use by local, State, or Federal land management agencies, is obtained and remains valid throughout the surface mining activities.

(2) Specific plans are prepared and submitted to the regulatory authority which show the feasibility of the postmining land use as related to projected land use trends and markets and that include a schedule showing how the proposed use will be developed and achieved within a reasonable time after mining and will be sustained. The regulatory authority may require appropriate demonstrations to show that the planned procedures are feasible, reasonable, and integrated with mining and reclamation, and that the plans will result in successful reclamation.

(3) Provision of any necessary public facilities is ensured as evidenced by letters of commitment from parties other than the person who conducts surface mining activities, as appropriate, to provide the public facilities in a manner compatible with the plans submitted under 30 CFR 780.23. The letters shall be submitted to the regulatory authority before surface mining activities begin.

(4) Specific and feasible plans are submitted to the regulatory authority which show that financing, attainment and maintenance of the postmining land use are feasible and, if appropriate, are supported by letters of commitment from parties other than the person who conducts the surface mining activities.

(5) Plans for the postmining land use are designed under the general supervision of a registered professional engineer, or other appropriate professional, who will ensure that the plans conform to applicable accepted standards for adequate land stability, drainage, vegetative cover, and esthetic design appropriate for the postmining use of the site.

(6) The proposed use will neither present actual or probable hazard to public health or safety nor will it pose any actual or probable threat of water flow diminution or pollution.

(7) The use will not involve unreasonable delays in reclamation.

(8) Necessary approval of measures to prevent or mitigate adverse effects

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on fish, wildlife, and related environmental values and threatened or endangered plants is obtained from the regulatory authority and appropriate State and Federal fish and wildlife management agencies have been provided a 60 day period in which to review the plan before surface mining activities begin.

(9) Proposals to change pre-mining land uses of range, fish and wildlife habitat, forest land, hayland, or pasture to a postmining cropland use, where the cropland would require continuous maintenance such as seeding, plowing, cultivation, fertilization, or other similar practices to be practicable or to comply with applicable Federal, State, and local laws, are reviewed by the regulatory authority to ensure that —

(i) There is a firm written commitment by the person who conducts surface mining activities or by the landowner or land manager to provide sufficient crop management after release of applicable performance bonds under Subchapter J and Sections 816.111-816.117, to assure that the proposed postmining cropland use remains practical and reasonable;

(ii) There is sufficient water available and committed to maintain crop production; and

(iii) Topsoil quality and depth are sufficient to support the proposed use.

APPENDIX II

SOIL CONSERVATION SERVICE
RANGE CONSERVATIONISTS

as of
April 1981

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APPENDIX III
Scales and Equivalents (Maps and Photographs)

Scales and Equivalents (Maps and Photographs)

Scale	Feet per Inch	Inches per 1000 Feet	Inches per Mile	Miles per Inch	Meters per Inch	Acres per Square Inch	Square Inches per Acre	Square Miles per Square Inch	CM per KM
1: 500	41.667	24.000	126.720	0.008	12.700	0.0399	25.0910	0.00006	200.000
1: 600	50.000	20.000	105.600	0.009	15.240	0.0574	17.4240	0.00009	166.670
1: 1,000	83.333	12.000	63.360	0.016	25.400	0.1594	6.2730	0.00025	100.000
1: 1,200	100.000	10.000	52.800	0.019	30.480	0.2296	4.3560	0.00036	83.330
1: 1,500	125.000	8.000	42.240	0.024	38.100	0.3587	2.7860	0.00056	66.670
1: 2,000	166.667	6.000	31.680	0.032	50.800	0.6377	1.5680	0.00100	50.000
1: 2,400	200.000	5.000	26.400	0.038	60.960	0.9183	1.0890	0.00140	41.670
1: 2,500	208.333	4.800	25.344	0.039	63.500	0.9964	1.0040	0.00160	40.000
1: 3,000	250.000	4.000	21.120	0.047	76.200	1.4348	0.6970	0.00220	33.330
1: 3,600	300.000	3.333	17.600	0.057	91.440	2.0661	0.4840	0.00320	27.780
1: 4,000	333.333	3.000	15.840	0.063	101.600	2.5508	0.3920	0.00400	25.000
1: 4,800	400.000	2.500	13.200	0.076	121.920	3.6731	0.2720	0.00570	20.820
1: 5,000	416.667	2.400	12.672	0.079	127.000	3.9856	0.2510	0.00620	20.000
1: 6,000	500.000	2.000	10.560	0.095	152.400	5.7392	0.1740	0.00900	16.670
1: 7,000	583.333	1.714	9.051	0.110	177.800	7.8117	0.1280	0.01220	14.290
1: 7,200	600.000	1.667	8.800	0.114	182.880	8.2645	0.1210	0.01290	13.890
1: 7,920	660.000	1.515	8.000	0.125	201.168	10.0000	0.1000	0.01560	12.630
1: 8,000	666.667	1.500	7.920	0.126	203.200	10.2030	0.0980	0.01590	12.500
1: 8,400	700.000	1.429	7.543	0.133	213.360	11.2490	0.0890	0.01760	11.900
1: 9,000	750.000	1.333	7.041	0.142	228.600	12.9130	0.0770	0.02020	11.110
1: 9,600	800.000	1.250	6.600	0.152	243.840	14.6920	0.0680	0.02300	10.420
1: 10,000	833.333	1.200	6.336	0.158	254.000	15.9420	0.0630	0.02490	10.000
1: 10,800	900.000	1.111	5.867	0.170	274.321	18.5950	0.0540	0.02910	9.259
1: 12,000	1,000.000	1.000	5.280	0.189	304.801	22.9570	0.0440	0.03590	8.333
1: 12,500	1,041.662	0.960	5.069	0.197	317.505	24.9100	0.0400	0.03850	8.000
1: 13,200	1,100.000	0.909	4.800	0.208	335.281	27.7780	0.0360	0.04340	7.576
1: 14,400	1,200.000	0.833	4.400	0.227	365.761	33.0580	0.0300	0.05170	6.944
1: 15,000	1,250.000	0.800	4.224	0.237	381.001	35.8700	0.0280	0.05600	6.667
1: 15,600	1,300.000	0.769	4.062	0.246	396.241	38.7970	0.0260	0.06060	6.410
1: 15,840	1,320.000	0.758	4.000	0.250	402.337	40.0000	0.0250	0.06250	6.313
1: 16,000	1,333.333	0.750	3.960	0.253	406.400	40.8120	0.0240	0.06380	6.250
1: 16,800	1,400.000	0.714	3.771	0.265	426.721	44.9950	0.0220	0.07030	5.952
1: 18,000	1,500.000	0.667	3.520	0.284	457.201	51.6530	0.0190	0.08070	5.556
1: 19,200	1,600.000	0.625	3.300	0.303	487.681	58.7700	0.0170	0.09180	5.208
1: 20,000	1,666.667	0.600	3.168	0.316	508.002	63.7690	0.0160	0.09960	5.000
1: 20,400	1,700.000	0.588	3.106	0.322	518.161	66.3450	0.0150	0.10370	4.902
1: 21,120	1,760.000	0.568	3.000	0.333	536.449	71.1110	0.0140	0.11110	4.735
1: 21,600	1,800.000	0.556	2.933	0.341	548.641	74.3800	0.0130	0.11620	4.630
1: 22,800	1,900.000	0.526	2.779	0.360	579.121	82.8740	0.0120	0.12950	4.386
1: 24,000	2,000.000	0.500	2.640	0.379	609.601	91.8270	0.0110	0.14350	4.167
1: 25,000	2,083.333	0.480	2.534	0.395	635.001	99.6390	0.0100	0.15570	4.000
1: 31,680	2,640.000	0.379	2.000	0.500	804.674	160.0000	0.0060	0.25000	3.157
1: 33,333	2,777.778	0.360	1.901	0.526	846.683	177.1360	0.0056	0.38640	3.000
1: 48,000	4,000.000	0.250	1.320	0.758	1,219.202	367.3090	0.0030	0.57390	2.083
1: 50,000	4,166.667	0.240	1.267	0.789	1,270.025	398.5560	0.0025	0.62270	2.000
1: 62,500	5,208.333	0.192	1.014	0.986	1,587.503	622.7440	0.0016	0.97300	1.600
1: 63,360	5,280.000	0.189	1.000	1.000	1,609.347	640.0000	0.0016	1.00000	1.578
1: 75,000	6,250.000	0.160	0.845	1.184	1,905.038	896.7520	0.0011	1.40120	1.333
1: 96,000	8,000.000	0.125	0.660	1.515	2,438.405	1,469.2400	0.0007	2.29570	1.042
1: 100,000	8,333.333	0.100	0.634	1.578	2,540.050	1,594.2250	0.0006	2.49100	1.000
1: 125,000	10,416.667	0.096	0.507	1.973	3,175.006	2,490.9800	0.0004	3.89220	0.800
1: 126,720	10,560.000	0.095	0.500	2.000	3,218.694	2,560.0000	0.0004	4.00000	0.789
1: 250,000	20,833.333	0.048	0.253	3.946	6,350.012	9,963.9070	0.0001	15.56860	0.400
1: 253,440	21,120.000	0.047	0.250	4.000	6,437.389	10,244.2020	0.0001	16.00000	0.395
1: 300,000	25,000.000	0.040	0.211	4.735	7,620.015	14,348.0260	0.0001	22.41880	0.333
1: 500,000	41,666.667	0.024	0.127	7.891	12,700.025	39,855.6270	—	62.27440	0.200
1:1,000,000	83,333.333	0.012	0.063	15.783	25,400.050	159,422.5070	—	249.09770	0.100

October 1978

APPENDIX IV

SOURCES OF REMOTELY SENSED DATA

Compiled by
Applications Branch
EROS Data Center

NATIONAL CARTOGRAPHIC INFORMATION CENTER (NCIC)
(formerly the Map Information Office)

NCIC was established within the USGS to provide a single-point contact source for cartographic-related information, including remotely sensed data. A computerized indexing system, the Aerial Photography Summary Record System (APSRS), shows all holdings of Federal agencies, with the long range goal of including data acquired on the state and local levels and (eventually) by private industry.

The system directs the user to a particular agency which holds coverage over a particular unit area, based on the 7½ minute USGS quadrangle system. The data will remain in the hands of the source agency.

The cooperating Federal agencies include:

- U.S. Geological Survey (USGS)
- National Oceanic and Atmospheric Administration (NOAA)
- Agricultural Stabilization and Conservation Service (ASCS)
- Bureau of Land Management (BLM)
- National Archives and Records Service (NARS)
- U.S. Forest Service (USFS)
- Library of Congress, Geography and Map Division
- Soil Conservation Service (SCS)
- Tennessee Valley Authority (TVA)
- Department of Defense (DOD)
- U.S. Army Corps of Engineers (USACA)

To provide easier access to NCIC at the regional level, there are NCIC offices at four USGS mapping centers:

NCIC Eastern
U.S. Geological Survey
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: (703) 860-6336

NCIC Midcontinent
U.S. Geological Survey
1400 Independence Road
Rolla, MO 65401
FTS: 276-9107
Comm: (314) 364-3680

NCIC Rocky Mountain
U.S. Geological Survey
Stop 504, Box 25046
Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: (303) 234-2326

NCIC Western
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2427
Comm: (415) 323-2427

The EROS Data Center was established in 1971 as part of the Earth Resources Observation Systems (EROS) program of the Department of Interior, and is managed by the U.S. Geological Survey. It provides primary access to Landsat data, aerial photography acquired by the DOI, and aerial photography and other remotely sensed data acquired by NASA Research Aircraft and from Skylab, Apollo, and Gemini spacecraft.

Landsats 1, 2, and 3 have acquired approximately 280,000 individual scenes in four separate spectral bands. Nearly complete coverage of the world's land areas, except the polar areas, has been collected. Over 40,000 frames of Skylab, Apollo, and Gemini coverage have been archived at EDC. Only selected coverage was taken on these missions.

High altitude aerial photography (taken from 60,000 to 65,000 feet altitude) has been acquired by NASA for much of the United States at the request of investigators participating in the NASA Earth Resources Program. The most common scales are 1:60,000 and 1:120,000. Black-and-white, color, and color infrared photographs are generally available in a 9" film format. Since the inception of this program in 1964, approximately 1,300,000 frames have been acquired, covering about 80% of the contiguous 48 states. Many areas have been flown more than once. Main inputs for this data are the NASA-Ames Research Center in Moffett Field, California, and the NASA-Johnson Space Center in Houston, Texas.

Conventional aerial photography flown by the USGS accounts for approximately 2,000,000 frames. The most common scale is 1:24,000, typically on 9" black-and-white panchromatic film.

A final category includes aerial photography acquired by various Federal agencies at various scales and film types. The following groups have input approximately 1,000,000 frames into the EDC archives:

- Army Map Service, Air Force, Navy
- U.S. Army Corps of Engineers
- Bureau of Land Management
- Bureau of Reclamation
- Wallops and Marshall Flight Centers (NASA)
- Mississippi Test Facility
- University of Michigan
- South Dakota State University

Since the EROS Data Center does not hold the complete collection of aerial photography acquired by these individual groups, users should contact the originating agency for the possibility of additional coverage. For more information contact:

EROS Data Center
Attn: User Services
Sioux Falls, SD 57198
FTS: 784-7151
Comm: (605) 594-6511, Ext. 151

U.S. BUREAU OF LAND MANAGEMENT

The BLM acquired photography in recent years at various scales and film types. For more information, contact:

> Mr. Wallace Crisco
> Office of Special Mapping
> Bureau of Land Management
> Denver Federal Center
> Building 50
> Denver, CO 80225
> FTS: 234-6036, 6037
> Comm: (303) 234-6036, 6037

AGRICULTURAL STABLIZATION AND CONSERVATION SERVICE (ACSC)

The ASCS has acquired coverage over about 80% of the United States excluding Alaska. Most commonly, surveys are flown at a scale of 1:20,000 on black and white 9" panchromatic film. Coverage is usually flown on a county-by-county basis on a 7 year cycle, dating back to the 1930's. Since about 1971, 1:40,000 scale photography has been acquired. Indexes of coverage for specific areas are available for inspection through the local county ASCS office. For more information contact:

> Aerial Photography Field Office
> ASCS - USDA
> 2222 West 2300 South
> P.O. Box 30010
> Salt Lake City, UT 84125
> FTS: 588-5856
> Comm: (801) 524-5856

SOIL CONSERVATION SERVICE (SCS)

The SCS has acquired conventional aerial photography for many areas of the United States. Coverage was generally acquired at a scale of 1:20,000 on 9" black and white panchromatic film. Most recently, coverage has been acquired at scales ranging from 1:31,680 to 1:85,000. The SCS is currently undertaking orthophoto mapping projects with cooperation from the USGS. Surveys are not flown on a prescribed repetitive basis. For more information contact:

> Soil Conservation Service, USDA
> Cartographic Division
> Federal Center Bldg.
> Hyattesville, MD 20782
> Comm: (301) 436-8187

NATIONAL ARCHIVES AND RECORDS SERVICE

This center is the archive for resource photography acquired by the ASCS, SCS, USGS, and the USBR prior to World War II. A catalog entitled "Aerial Photographs in the National Archives" is available upon request. For more information contact:

> National Archives and Records Service
> Cartographic Branch
> General Services Administration
> Washington, DC 20408
> Tele: (205) 523-3006

U.S. FOREST SERVICE (USFS)

The USFS has acquired aerial photography over most of the National Forest lands. Photography is primarily at scales of 1:20,000 to 1:24,000 on standard black and white 9" panchromatic film, and dates back to 1934. Standard coverage through the 1960's was at a scale of 1:15,840. More recently, color and color IR photography at smaller scales ranging up to 1:80,000 has been acquired. Coverage is updated as is deemed necessary by the USFS.

The Forest Service is geographically organized into nine regions with the regional headquarters listed below.

Region 1
Northern
Federal Bldg.
Missoula, MT 59801

Region 2
Rocky Mt.
11177 W. 8th Ave.
Box 25127
Lakewood, CO 80225

Region 3
Southwestern
517 Gold Ave., SW
Albuquerque, NM 87102

Region 4
Intermountain
324 25th St.
Ogden, UT 84401

Region 5
California
630 Sansome St., Room 548
San Francisco, CA 94111

Region 6
Pacific Northwest
319 SW Pine St.
P.O. Box 3623
Portland, OR 97208

Region 7
Does not exist

Region 8
Southern
1720 Peachtree Rd.
Atlanta, GA 30309

Region 9
Eastern
633 West Wisconsin Ave.
Milwaukee, WI 53203

Region 10
Alaska
Federal Office Bldg.
P.O. Box 1628
Juneau, AK 99502

Inquires may also be referred to:

Division of Engineering
U.S. Forest Service, USDA
Washington, DC 20250

NATIONAL PARK SERVICE (NPS)

The NPS has acquired aerial photography over the national parks at various scales with film types. For more information contact:

National Park Service
Denver Service Center
655 Parfet St.
P.O. Box 25287
Denver, CO 80225
Tele: (303) 234-5132
FTS: 234-4500

ENVIRONMENTAL PROTECTION AGENCY (EPA)

In 1974 EPA established a Remote Sensing Branch at the National Environmental Research Center in Las Vegas, Nevada. The data acquired are of various types and formats. For more information contact:

Environmental Protection Agency   or: EPA Interpretation Center
Remote Sensing Branch   P.O. Box 1587
P.O. Box 15027   Vint Hill Farms
Las Vegas, NV 89114   Warrenton, VA 22186

DEPARTMENT OF DEFENSE (DOD)

Estimates of the amount of aerial photography acquired by the DOD run between 100 - 200 million frames. The primary agency responsible for archiving this collection is the Defense Intelligence Agency (DIA). Photograph was generally acquired by conventional means at scales of 1:15,000 - 1:40,000 on 9" black-and-white panchromatic film. Coverage dates back to the 1930's. Some of the early coverage, such as the AMS small scale coverage of the 1950's and the Navy/Army-acquired coverage of Alaska, has been transferred to the EDC archives. NCIC is currently handling the task of producing plots and indexes of DOD unclassified coverage.

The Defense Mapping Agency (DMA) was established in 1972, with primary responsibilities for mapping and charting within the DOD. Most current activities are being worked out in conjunction with the USGS.

For more information contact:

Defense Mapping Agency   Defense Intelligence Agency
Topographic Command   Att: DS4A
6500 Brooks Lane, NW   Arlington Hall Station
Washington, DC 20315   Washington, DC 20301
Att: Code 50320

U.S. ARMY CORPS OF ENGINEERS

The USACE has extensive involvement in civil projects such as dams, shoreline and flood protection, and waterway navigation. Aerial photographic coverage dating back to the 1930's was generally acquired with standard 9" black-and-white panchromatic film. Scales vary considerably with particular project requirements. More recently, coverage has been acquired using color and color IR film types. Although USACE is officially part of the DOD, most of its more recent coverage remains in the hands of the particular project office that collected it. The principal USACE organizations involved with remote sensing data are:

(A) Engineer Topographic Laboratories (ETL)
(B) Cold Regions Research and Engineering Laboratory (CRREL)
(C) Waterways Experiment Station (WES)
(D) Coastal Engineering Research Center (CERC)
(E) Construction Engineering Research Laboratory (CERL)
(F) Institute for Water Resources (IWR)

The Coastal Engineering Research Center at Ft. Belvoir, VA, has recently taken the responsibility of indexing much of the imagery collected by the Corps.

For more information, contact the USACE Remote Sensing Coordinator on the Division level.

Huntsville Division
William A. Newbern, Jr. - (HNDED-FC)
P.O. Box 1600 West Station
Huntsville, AL 35807
Tele: (205) 895-5190

North Central Division
Mack L. Dixon - (NCDPD-PF)
536 S. Clark St.
Chicago, IL 60605
Tele: (312) 353-6395

Lower Mississippi Valley Division
Todd H. Riddle - (LMVED-G)
P.O. Box 80
Vicksburg, MS 39180
Tele: (601) 636-1311 ext. 339
                 or ext. 611

North Pacific Division
Billy J. Thomas - (NPDEN-WC)
Room 210 Custom House
Portland, OR 97209
Tele: (503) 221-3757

Missouri River Division
Charles G. Flagg-(MRDED-G)
P.O. Box 103 Downtown Station
Omaha, NE 68101
Tele: (402) 221-3204

Ohio River Division
Griffith Ray - (ORDED-T)
P.O. Box 1159
Cincinnati, OH 45201
Tele: (513) 684-3024

New England Division
Joseph Horowitz - (NEDED-W)
424 Trapelo Road
Waltham, MA 92154
Tele: (617) 894-2400 ext. 632

Pacific Ocean Division
Dr. James Maragos - (PODED-PV)
Bldg. 230, Ft. Shafter
Honolulu, HI 96813
Tele: (808) 438-2263

North Atlantic Division
Dave Leiser - (NADPL-F)
90 Church Street
New York, NY 10007
Tele: (212) 264-7088

South Atlantic Division
James W. Erwin - (SADEG)
510 Title Bldg.
30 Pryor St. NW
Atlanta, GA 30303
Tele: (404) 526-6704

South Pacific Division
David L. Sveum - (SPDED-H)
630 Sansome St., Room 1216
San Francisco, CA 94111
Tele: (415) 556-5709

Southwestern Division
John W. Murchison - (SWDED-F)
1200 Main Tower
Dallas, TX 75202
Tele: (214) 749-3166

Field Operating Agencies

Coastal Engineering Research Center
Dennis Berg - (CERVE)
Kingman Bldg.
Ft. Belvoir, VA 22060
Tele: (703) 325-7172

Cold Regions Research and
  Engineering Laboratory
Dr. Duwayne Anderson
P.O. Box 282
Hanover, NH 03755
Tele: (603) 643-3200

Construction Engineering Research
  Laboratory
Dr. R. K. Jain
P.O. Box 4005
Champaign, IL 61820
Tele: (217) 352-6511

Robert Frost
Engineer Topographic Laboratories
Ft. Belvoir, VA 22060
Tele: (703) 664-3736

Institute for Water Resources
Kingman Bldg.
Ft. Belvoir, VA 22060

Waterways Experiment Station
Warren E. Grabau
P.O. Box 631
Vicksburg, MS 39180
Tele: (601) 636-3111

NATIONAL OCEAN SURVEY - COASTAL MAPPING DIVISION

     The Coastal Mapping Division (formerly the Coast and Geodetic Survey) has
acquired coverage over the nation's coastal areas. Multispectral metric mapping
type coverage at scales ranging from 1:10,000 to 1:40,000 has been acquired in
recent years. This agency also has the responsibility for acquiring aerial
photography over the nation's major airports, back to World War II under the
"Airport Obstruction Chart Survey Program." Coverage is typically
black-and-white panchromatic with scales varying from 1:24,000 to 1:60,000. For
more information contact:

                    Coastal Mapping Division
                    NOAA
                    Rockville, MD 20852
                    Tele: (301) 496-8601

DEFENSE METEOROLOGICAL SATELLITE PROGRAM (DMSP)

     Data acquired by the USAF Global Weather Satellite Program is archived at
the Space Science and Engineering Center at the University of Wisconsin. This
data originates at USAF Global Weather Central, Offutt AFB, Omaha, NE. For more
information contact:

DMSP Satellite Data Library
Space Science and Engineering Center
University of Wisconsin
1225 West Dayton Street
Madison, WI 53706
Tele: (608) 262-5335

WALLOPS FLIGHT CENTER (NASA)

Wallops Flight Center has an active remote sensing program centered around
its Chesapeake Bay Ecological Program. Generally, this is low to middle
altitude multispectral photography. For more information contact:

Chesapeake Bay Ecological
  Program Office
NASA-Wallops Flight Center
Wallops Island, VA 23337
Tele: (804) 824-3411 ext. 260

TENNESSEE VALLEY AUTHORITY

The TVA has acquired conventional aerial photography of the Tennessee River
watershed area which includes the state of Tennessee and adjoining portions of
Alabama, Georgia, Kentucky, Mississippi, North Carolina, and Virginia.
Coverage, dating back to 1933, was taken at various scales although typically at
1:24,000. Recently, some special purpose color and color IR coverage has been
acquired. For more information contact:

Map Information and Records Unit
Maps and Surveys Branch
Tennessee Valley Authority
101 Haney Bldg.
Chattanooga, TN 37401
Tele: (615) 755-2122

PRIVATE AERIAL SURVEY COMPANIES

If existing coverage is not suitable, it may be necessary to contract for
new photography to be flown. A good source of names of aerial survey firms is:

American Society of Photogrammetry
105 North Virginia Avenue
Falls Church, VA 22046
Tele: (703) 534-6617

ENVIRONMENTAL SATELLITE IMAGERY

Low resolution imagery of the Earth is being acquired using visible and
thermal infrared sensors by a variety of environmental satellites, including
SMS-GOES, TIROS, Nimbus, ATS, and ESSA satellites. For more information
contact:

Satellite Data Services Branch D543
                    Environmental Data Service
                    National Oceanic and Atmospheric
                      Administration (NOAA)
                    World Weather Bldg. - Room 606
                    Washington, DC 20233
                    Tele: (301) 763-8111

                 SOURCES OF REMOTELY SENSED DATA IN CANADA

For aerial photography, contact: Landsat data can be purchased directly from:

National Air Photo Library   Integrated Satellite Information Services
615 Booth Street   (ISIS) Ltd
Ottawa, Ontario K1A 0E9   P.O. Box 1630
Canada   Prince Albert, Saskatchewan S6V 5T2
Tele: (613) 995-4597   Canada
Telex: 053-4328   Tele: (306) 764-3602 764-4259
                                    Telex: 074-29242

     Landsat data availability and ordering assistance (also information
regarding airborne remotely sensed data) are provided by:

                    Canada Centre for Remote Sensing
                    Attn: User Assistance
                    717 Belfast Road
                    Ottawa, Ontario K1A 0Y7
                    Canada
                    Tele: (613) 995-1210
                    Telex: 053-3777

                    Regional NCIC and EROS Offices

    1. National Cartographic Information Center (NCIC) - national headquarters

        U.S. Geological Survey
        National Cartographic Information Center
        507 National Center
        Reston, VA 22092
        (703) 860-6045, FTS: 928-6045

    2. NCIC Regional Mapping Centers

Mr. Raymond E. Hill   Mr. Frederick G. Lavery
U.S. Geological Survey   U.S. Geological Survey
Rocky Mountain Mapping Center   Eastern Mapping Center
National Cartographic Information Center National Cartographic Information
Stop 510, Box 25046, Federal Center   536 National Center
Denver, CO 80225   Reston, VA 22092
(303) 234-2326, FTS: 234-2326   (703) 860-6336, FTS: 928-6336

Mr. Lee W. Aggers
U.S. Geological Survey
Western Mapping Center
National Cartographic Information Center
345 Middlefield Road
Menlo Park, CA 94025
(415) 323-8111, ext. 2427, FTS: 467-2427

Mr. William M. Voight
U.S. Geological Survey
Mid-Continent Mapping Center
National Cartographic Information
  Center
1400 Independence Road
Rolla, MO 65401
(314) 364-3680, ext. 107,
FTS: 276-9107

3. NCIC Federal Affiliate

Maurice Msarsa
Maps and Surveys Branch
Tennessee Valley Authority
200 Haney Building
311 Broad Street
Chattanooga, TN 37401
(615) 755-2148, FTS: 854-2148

4. NCIC Other Affiliates

Mr. Kent N. Swanjord
U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198
(605) 594-6511, ext. 507,
FTS: 784-7507

Mr. Henry T. Svehlak
U.S. Geological Survey
National Space Technology Laboratories
National Cartographic Information Center
Building 1100
NSTL Station, MS 39529
(601) 688-3544, FTS: 494-3544

5. NCIC State Affiliates

Arizona

Mr. Michael S. Castro
Arizona Department of Revenue
Arizona Resources Information
  System
1624 West Adams, Room 302
Phoenix, AZ 85007
(602) 271-4061, FTS: 765-4061

Minnesota

Dr. Donald Yeager
Minnesota State Planning Agency
Environmental State Planning Agency
15 Capitol Square
550 Cedar Street
St. Paul, MN 55101
(612) 296-2613, FTS: 776-2613

Georgia

Mr. Keith McConnell
Branch of Geology and Water Resources
Geologic & Water Resources Division
Department of Natural Resources
19 Martin Luther King Drive
Atlanta, GA 30334
(404) 656-3214, FTS: 656-3214

New Mexico

Dr. Stanley A. Morain
  Technology Applications Center
University of New Mexico
2500 Central Avenue, SE
Albuquerque, NM 87131
(505) 277-3622

Pennsylvania

Mr. Don Hoskins
Department of Environmental Resources
Room 916 Executive House
Bureau of Topographic and
  Geological Survey
P.O. Box 2357
Harrisburg, PA 17120
(717) 787-2169, FTS: 637-2169

South Carolina

Mr. Nick Bayne
South Carolina Land Resources
  Conservation Commission
2221 Devine Street, Suite 222
Columbia, SC 29205
(803) 758-7197, ext. 41

Tennessee

Mr. Ron Zurawski
Tennessee Division of Geology
Room G-5
State Office Building
Nashville, TN 37219
(615) 741-2726, FTS: 840-2726

Texas

Mr. David L. Ferguson
Texas Natural Resources Information
  System
P.O. Box 13087
Austin, TX 78711
(512) 475-3321, FTS: 734-5011

Utah

Mr. Donald T. McMillan
Utah Geological and Mineralogical
  Survey
606 Black Hawk Way
Research Park
Salt Lake City, UT 84108

West Virginia

Dr. Peter Lessing
West Virginia Geological and
  Economic Survey
West Virginia Cartographic Center
P.O. Box 879
Morgantown, WV 26505
(304) 292-6331, ext. 256

6.   EROS Applications Assistance Facilities (AAF)

Alaska

EROS Applications Assistance Facility
University of Alaska
Geophysical Institute
College, AK 99701
(907) 479-7558

Canal Zone

EROS Applications Assistance Facility
HQ Inter-American Geodetic Survey
Headquarters Building
Drawer 934
Fort Clayton, Canal Zone
Phone: 83-3897

Virginia

EROS Applications Assistance Facility
U.S. Geological Survey
1925 Newton Square East
Reston, VA 22090
(703) 860-7868

STATE NATURAL RESOURCE INFORMATION SYSTEMS

SYSTEM NAME	CONTACT	PHONE
Alabama Resource Information System (ARIS)	Walter Stevenson	(205) 832-6400
Arizona Resource Information System (ARIS)	Mike Castro	(602) 271-4061
Georgia Resource Assessment Program	Bruce Rado	(404) 656-5164
Iowa Water Resources Data System (IWARDS)	Bernie Hoyer	(319) 338-1173
Louisana Areal Resource Information System (LARIS)	Glenn Daigre	(504) 925-4585
Maryland Automated Geographic Information System (MAGI)	John Antenucci	(301) 383-2472
Minnesota Land Management Information System (MLMIS)	Alan Robinette	(612) 296-1211
Mississippi Data Management System	Eddy Downing	(601) 982-6339
Montana Geo-Data System	Tom Dundas	(406) 449-2896
New Jersey Geographic Base File	Bob Mills	(609) 292-2855
New York Land Use and Natural Resources Inventory (LUNR)	Chuck Guinn	(518) 474-7690
North Carolina Land Resource Information System (LRIS)	Jim Haddox	(919) 733-3833
North Dakota Regional Environmental Assessment Program (REAP)	Rich Giddings	(701) 224-3700
Ohio Capability Analysis Project (OCAP)	Garry Schaal	(614) 466-6557
South Carolina (Not yet named)	Nick Bayne	(803) 777-7237
South Dakota Land Resource Information System (LRIS)	Jerry Schlesinger	(605) 715-3628
Texas Natural Resources Information System (TNRIS)	John Wilson	(512) 475-3321
Virginia Resource Information System (VARIS)	Bill Breen	(804) 786-7831

Note: Compiled by: Remote Sensing Project
                      National Conference of State Legislatures (NCSL)
                      1405 Curtis St., 23rd Floor
                      Denver, CO 80202

                      This listing appeared in the February 1979 issue of
                      NCSL's "Remote Sensing, a Review of State Landsat
                      Applications"

APPENDIX V

SELECTED BOOKS ON MAPS AND MAPPING

All About Maps and Mapping
    Susan Marsh; Random House, 1963.
Be Expert With Map and Compass: The Orienteering Handbook
    Bjorn Kjellstrom; Scribner & Sons, 1976.
Cartographic Design and Production
    J.S. Keates; Halsted Press, 1976.
Computers and the Renaissance of Cartography
    T.A. Margerison; Her Majesty's Stationery Office, 1976.
Coordinate Systems and Map Projections
    D.H. Maling; George Philip & Son, Ltd., 1973.
Easy Steps to Map Reading
    Kathleen Howard; J.M. Dent & Sons, Ltd., 1958.
Elementary Map Reading
    Thomas Pickles; J.M. Dent & Sons, Ltd., 1950.
Elements of Cartography
    A.H. Robinson, R.D. Sale, and J. Morrison; John S. Wiley & Sons, Inc., Third Edition, 1978.
Elements of Map Projection with Applications to Map and Chart Construction
    U.S. Government Printing Office, 1931 (Reprint 1972).
Elements of Photogrammetry
    P.R. Wolf, McGraw-Hill, 1974.
First Book of Maps and Globes
    S. Epstein and B. Epstein; Franklin Watts, Inc., 1959.
General Cartography
    Erwin Raisz; McGraw-Hill Book Co., 1948.
Going Places U.S.A.
    William D. Pattison, Rand McNally and Co., 1977.
How Maps and Globes Help Us
    David Hackler; Benefic Press, 1962.
Introduction to Mapwork
    L.H. Williams; Allman and Son, 1968.
Introductory Map Reading
    I.C. Marshall and A.H. Meux; Univ. of London Press, Ltd., 1966.
Landforms and Topographic Maps
    William Bayley Upton, Jr.; John Wiley & Sons, 1970.
The Language of Topographic Maps
    D.S. Biddle, A.K. Milne and D.A. Shortle; Jacaranda Press, Australia, 1974.
Learning to Use a Map
    P.L. Ewing and R.O. Smith, A.J. Nystrom and Co., 1977.
Look at the Map
    Cyril Midgley; Whitcombe and Tombs, Ltd., 1968.
The Magic Map
    Cyril Midgley; Wheaton Publishing Co., 1967.
Manual of Photogrammetry
    Morris M. Thompson; American Society of Photogrammetry, 1966.
Map and Globe Activities for Children
    Paul F. Griffin; Fearon Publishers, Inc., 1957.
Map and Photo Reading
    Thomas W. Birch; Edward Arnold, Ltd., 1968.
Map, Compass, and Campfire
    Donald E. Ratliff; Binford and Mort, 1970.
A Map is a Picture
    B. Rinkoff; Thomas Y. Crowell Co., 1965.

Mapmakers of America from the Age of Discovery to the Space Age
    S. Carl Hirsch; Viking Press, 1970.
Map Making: The Art That Became A Science
    Lloyd A. Brown; Little, Brown & Co., 1960.
Map Reading and Interpretation
    P. Speak and A.H. Carter; Longmans, Ltd., 1970.
Map Reading for Schools
    Margaret Wood; George G. Harrap & Co., Ltd., 1964.
Map Reading in Geography
    Kenneth B. Cumberland; Whitcomb and Tombs, Ltd., 1968.
Map Reading through Map Making
    D.D. Harris; Whitcomb and Tombs, Ltd., 1966.
Maps and Diagrams, Their Compilation and Construction
    F.J. Monkhouse and H.R. Wilkinson; Methuen & Co., 1971.
Maps of the Ancient Sea Kings
    C.H. Hapgood; Chilton Book Publishers, 1966.
Maps Mean Adventure
    Cristle McFall; Dodd, Mead & Co., 1972.
The Map Unfolds
    Cyril Midgley; Wheaton Publishing Co., 1969.
Mapping
    David Greenhood; University of Chicago Press, 1964.
Mapping the World
    Erwin Raisz; Abelard Schuman, Ltd., 1956.
Maps and Man
    Norman J.W. Thrower; Prentice-Hall, Inc., 1972.
Maps and Mapping
    B. Butterfield; Doubleday & Co., Inc., 1966.
Maps and Their Makers: An Introduction to the History of Cartography
    G.R. Crone; Shoe String, 1977.
Math Projects: Map-Making
    H.E. Tannenbaum and N. Stillman; Book Lab, Inc., 1968.
Physical Geography in Diagrams
    R.B. Bunnett; Longmans, Ltd., 1973.
Principles of Cartography
    Erwin Raisz, McGraw-Hill Book Co., 1962.
Rand McNally Handbook of Map and Globe Usage
    Ruby M. Harris, Rand McNally and Co., 1967.
Reading Maps
    Paul A. Riffel; Hubbard Press, 1973.
Reading Topographical Maps
    A.H. Meux; Hodder Educational, 1975.
The Round Earth on Flat Paper
    National Geographic Society, 1947.
The Story of Maps
    M. Schere; Prentice Hall, Inc., 1969.
Surveying
    Boy Scouts of America, 1960.
Surveying Practice: The Fundamentals of Surveying
    Philip Kissam; McGraw-Hill, 1978.
Surveyors and Surveys of the Public Lands
    Bureau of Land Management, Department of Interior; Government Printing Office, 1976.
Teaching About Maps Grade by Grade
    Susan Marsh; Teachers Publishing Corps., 1965.
The True Book of Maps
    Norman and Madelyn Carlisle; Childrens Press, 1969.
The World of Maps and Mapping
    Judith Tyner; McGraw-Hill, 1973.

APPENDIX VI

A Set of Random Numbers

Column 1	Column 2	Column 3	Column 4
6327	0983	3798	4679
2167	6484	9467	9058
5939	0407	1804	8827
4672	3865	5689	9878
8071	5185	5514	5308
9509	0603	7461	8550
6615	2588	3558	3349
4833	2422	9790	1183
5594	1809	6931	6571
9441	1699	3947	7702
7922	9812	7229	5252
9419	6494	8179	8065
6178	3556	2466	2495
2647	3961	7546	4799
0474	1839	6926	6534
9814	1577	8293	0301
0104	4579	0627	8667
1608	9470	4131	5345
9722	1557	0471	5498
4189	3582	3675	9461
9855	8088	9006	6897
5791	8234	1472	3421
0872	3310	0510	9046
8953	9809	8037	8376
2895	4319	6544	8953
0609	5248	8734	2498
9795	2464	6170	1063
1572	7371	7936	2841
4307	0294	6060	5194
4857	0197	2401	7005
1632	7189	6463	9830
0745	8034	7882	7152
0736	5110	5165	6571
8168	7924	5876	1407
7468	5313	2736	9010
6044	5420	3077	9070
6716	0059	3001	8871
9342	0169	6880	7986
5809	6048	9051	1151
1532	9715	7081	0109
5506	5812	5917	4415
4045	1751	2817	9958
5966	9930	6437	7279
6062	3296	5093	2503
4097	8379	5670	0614
6793	3999	4645	5143
7960	4853	0583	1920
1321	4067	8503	1604

APPENDIX VII

Changing the Statistical Procedures to Meet Changes in the Regulations

The procedures described in the section on "Meeting Statistical Requirements" are adaptable to changes in the regulations.

1. If the confidence level changes, from 0.1, it is merely necessary to look up t-values which correspond to the new level of confidence. For example, when $n = 25$, and the level of confidence is 0.1, $t = 1.32$ (table 20). If $n = 25$, and the level of confidence is 0.05, $t = 1.71$.

2. If the percent of the reference area that the cover and production of the revegetated area must fall within changes, it will be necessary to change all equations in which 0.9, 0.81, and 1.81 occur. Two examples are provided below. The original value and how it was derived is shown under the 90 percent column. The values that would be substituted for 85 percent or 100 percent are shown in the next two columns.

90 percent	85 percent	100 percent
0.9	0.85	1.0
$0.81 = 0.9^2$	$0.72 = 0.85^2$	$1.0 = 1.0^2$
$1.81 = 1 + 0.81$	$1.72 = 1 + 0.72$	$2.0 = 1.0 + 1.0$

This handbook details methods of sampling vegetation for the comparison
of revegetated mine lands and reference areas as specified by Federal regula-
tions. Reference area selection, sampling schemes, and species diversity are
covered as well as production, cover, and density sampling methodology. A
statistical section outlines sample size determination and comparison of
reference and revegetated areas using confidence limit estimates.

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